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CONFERENCE WITH THE INDIAN SCIENTIFIC DELEGATION

THROUGH the Association's Division for the Social and International Relations of Science, a conference for the Indian Scientific Delegation visiting Great Britain was arranged in collaboration with the Indian Group of the Royal Institute of International Affairs. The conference was held, by kind permission of the Institute, in Chatham House, St. James's Square, London, on Friday, November 10, 1944.

The delegation consisted of the following representatives: Dr. Nazir Ahmad, Director of the Cotton Technological Laboratory, Matunga, Bombay; Colonel S. L. Bhatia, Deputy Director General of the I.M.S.; Sir Shanti S. Bhatnagar, F.R.S., Director of Scientific and Industrial Research, India; Sir Jnan Chandra Ghosh, Director of the Indian Institute of Science, Bangalore, and President of the National Institute of Science of India; Professor S. K. Mitra, of the University College of Science, Calcutta; Professor J. N. Mukherjee, Professor of Chemistry, Calcutta University; Professor Megh Nad Saha, F.R.S., of the University College of Science, Calcutta.

All these, excepting Col. Bhatia, were present and took part in the conference as reported below.

Sir Richard Gregory, Bt., F.R.S., President of the Association, took the chair, and at the outset called upon Sir Frederick Whyte, K.C.S.I., convener of discussions in the Royal Institute of International Affairs.

Sir Frederick Whyte, K.C.S.I.

I have been asked on behalf of the Royal Institute of International Affairs to say a word of introduction to these proceedings. It gives the Council very great pleasure to co-operate with the British Association in organising this meeting for our friends visiting us from India, and to offer the hospitality of the premises of Chatham House on an occasion of this sort. It is almost a platitude to say, but it was a very happy idea that our friends from India should have been invited to visit Great Britain at this moment, and our only doubt is that owing to the mixture of business and pleasure in which they are engaged, they may find themselves a little overburdened by both processes. However, perhaps the extent of the burden is the extent of their welcome. They are very welcome indeed under our roof, and I will pass the proceedings to Sir Richard Gregory.

Sir Richard Gregory, Bt., F.R.S.

I thank you for the welcome which you have extended to our guests, the visiting scientists from India, and Professor Saha in particular for being able to say something to us upon the wider relations of science to civilisation. It is most appropriate that we should meet here jointly in connection with a subject of that kind. Science is beginning really to be understood not only as a most important material study but also as a spiritual factor which determines the character of civilisation. It is an international study, and therefore can most appropriately be considered in this hall.

If there is one subject, rightly understood, which can bring people in the world together instead of separating them, it is science in all its aspects. The distinguished scientists from India have come here at this very important stage in the history of the world to make contacts with their colleagues in Great Britain. In addition to the scientific contacts which they are making through visits to various scientific institutes and societies and works, where scientific research and development are being carried on to a greater extent than ever before, it is most appropriate that here to-day, nearing the end of their visit, another aspect should be brought forward. That is the relations of this expanding knowledge of the universe in which we live and the relations of those facts to the development of the human race and the improvement of international relationships. Professor Saha is not only one of the most distinguished scientific workers in India but also is particularly concerned with the promotion of wide interest and wide knowledge of the meaning of their work to mankind. He is the editor of a journal in India which is increasing in its circulation and authority, a journal called *Science and Culture*, which is at the basis of most interests with which the Royal Institute of International Affairs is concerned. On that account he can express the wider view of what science means to the world otherwise than by dealing only with his specific subject of spectroscopic physics. He was a student at the Imperial College of Science in London under the late Professor Alfred Fowler, from whose laboratory he derived insight into atomic actions and reactions and their effects upon spectroscopic matters. I mention this only to indicate that although Professor Saha takes keen and active interest

in the promotion of awareness of science and the scientific spirit in modern life, yet he is also the leading authority upon a particular aspect of physics. I do not like to say his subject has no relation to what he has to say this afternoon, and yet I cannot help making a comparison between those atomic studies of his and the studies of the human atom with which he is also particularly concerned. In every chemical element, the electrons are attached to the atom by a certain power or potential called the tenacity of the atom. That is one quality which has to be taken into consideration, the attachment of these separate particles to the atom and the conditions which affect their arrangement. That principle, which he worked out in a mathematical way, has been the guiding point in connection with his studies to determine such conditions of temperature and pressure. These conditions decide whether the tenacity of the atom for the particle should resolve into the particle being maintained within the atom or whether it should go outside—whether there should be isolation or federation.

We have a certain amount of the same kind of thing in connection with human governments and human communities, whether certain parts should separate from the parent atom or not, and what real powers will maintain the electron within the atom, and what temperatures and pressures will let them depart and wander about until they are collected by another government or atom into another community.

Professor Saha, ten years ago, was the President of the Indian Science Congress Association, which is an Association similar to the British Association, holding annual meetings in different parts of India and bringing together different addresses by the various presidents in a similar way to the British Association. The British Association sent a large and important delegation to this Congress in 1938, and a number of members of that delegation are here to-day, to cement and increase the contacts between the Associations made then and now. It was the first occasion on which the British Association had visited India. Sir James Jeans was the President of the Congress at that time, and a very successful meeting was held.

So it seemed to the Council of the British Association that it was most appropriate in these times, when we have a very active Division for the Social and International Relations of Science, that we should mark this occasion, if possible, by inducing Professor Saha to speak upon such relationships. When he was President of the Indian Science Congress in 1934 he dealt in his address with this subject, and pointed out that under conditions existing to-day the world is a single economic and cultural unit. He then suggested, what is now very much in the air, that there should be a meeting of the foremost thinkers in the world to provide some scheme by which this unity should be promoted, and to institute an educational programme with that very object of making peoples everywhere realise that the world is now one in communications and in means of transport, that man is one, and that the world should be considered in that point of view instead of as separate and conflicting units. We may have far to go before that end is realised, and yet surely it is the right aim and object to have in view if the future for this world of ours is to be preserved from destruction through the misuse of the fruits of knowledge.

Prof. Megh Nad Saha, F.R.S.

When I was asked to address this Association on the rôle of science in social and international planning, I was just starting from India, and I added one line—' with special reference to India.' I do not think I can do full justice to this subject to-day, as we are moving from place to place, often in great haste, and nomadic life is not provocative of very serious thought, but I shall try to do my best. Sir Richard Gregory has said something about my work, done about twenty years ago, with respect to understanding the behaviour of atoms, but after twenty years scientists have learnt to be more modest, because we find that we have been dealing only with the surface, and it is only in recent years the scientists of the world have been trying to probe into the heart of the atom. We can say almost the same thing with respect to international affairs. It is a very difficult subject, for we have to take men as one unit and find out how all units should combine and co-operate and build up a better world ; but we have not made any great progress towards understanding the phenomenon ; probably we have been only playing on the surface, but actually we have not been able to come to the heart of the problem.

As you know, the League of Nations was formed to promote goodwill and peace among nations. We all regret it did not fulfil its mission, but it did undertake many useful surveys on international affairs, two of which specially engaged my attention. One was the Year Book published by the Labour Department, which showed in tabulated form the production of commodities in different political units of the world ; the other was very different—it was the report of the Committee appointed to frame an International Calendar for the whole world. I am mentioning these two items because

they both deal with international affairs, and, in spite of their widely divergent nature, they are in some measure related.

The Year Book must have been very largely used by economists, and I tried, as an amateur economist, to form out of its contents some idea about the comparative income of people of different countries of the world. This proved to be a rather hopeless task, but it was thought that an estimate of the same quantity might be obtained from an entirely different angle, namely, the energy-production in different countries, for we can take wealth to be directly proportional to the output of energy. This is comparatively an easier task, for the energy output—I am dabbling a little more in science—is measured by the sum total of work done by men and domesticated animals, and by the aid of engines using coal, petrol, and other kinds of fuel directly, or by electrical engines which may be run by electricity derived either from thermal or hydro-electric sources. It is true that forces of nature were harnessed to do useful work in medieval times as well, for example, by windmills, sails and water-wheels, but they were very inefficient, and the amount of work derived from these agencies must have been very small compared to that from animate agencies.

The League of Nations Year Book gave total production of electrical energy from thermal and hydro-electric sources for every country, so that it is a perfectly simple matter to calculate the *per capita* output in every country. We may call it by a shorter term, say, the energy-index for a country. In 1931 the figure was 650 for the U.K. ; 1,700 for Canada, 1,300 for Sweden, and I think in the neighbourhood of 1,500 for the U.S.A. These are the most advanced countries of the world, but we may also consider some backward countries. It was 180 for Mexico, and for other countries I have not the figure just now, but for India and China no figures were available. According to a Government of India estimate, however, the total production of electrical energy was only 3,500 million units in 1932, so it comes only to 9 units per head of the population. It is more difficult to calculate the energy production from coal and other fuel, for coal mined in or imported into any country has many other uses beside energy production and the efficiency of energy production varies within a wide range. I do not wish to bother you with all these technicalities, but it was concluded that the energy production from coal and other fuel in the U.K. was probably 1,300, and somewhat larger in the U.S.A. In India it could not have been more than 20, because India produces only 26,000,000 tons of coal compared with Britain's 200,000,000, and the use of Indian coal is extremely wasteful.

We therefore find that before the war the energy-index from inanimate sources amounted in Britain to about 2,000 and in the U.S.A. to about 2,500 ; in India it could not amount to more than 30, and even that is probably too liberal an estimate.

You might ask where the energy production by man and domesticated animals comes into this picture. A man working eight hours per day for three hundred days in the year produces only 180 units, and assuming that one-third of the population is engaged in productive work, which is not far from the truth, the average cannot be more than 60 units *per capita* per year. The energy production by animals, by wind and water power in the Middle Ages would not exceed 20 units, so we are not far from the truth if we say in the Middle Ages the energy-index amounted to about 80 units, with small variations from country to country. This is negligible compared with the energy-index in a modern country, from steam, electricity, and petrol, and can be almost entirely ignored.

These arguments are simple enough, but we can make some important deductions from them. One sees clearly that in advanced countries of the world, man, by harnessing the forces of nature, has increased the energy-index by 20 to 35 times within the last hundred years, and this has caused a very profound revolution in society. We are sometimes apt to think of ancient and medieval times in very romantic terms, but when we examine the conditions critically we find how much we have advanced. Critical historical research has shown that in medieval times the standards of living for the ordinary person and conditions of public health in every country were extremely low compared with modern standards. Only a few who possessed slaves could afford comforts, but it was not much compared with the standards enjoyed even by the average citizen in advanced countries of the world at the present epoch. In the sixteenth century even Royalties in Europe could not afford two baths in a month, and that was considered a luxury. There was terrible mortality among children, and even Royal children used to suffer heavy casualties due to disease now found preventable ; and all this is due to modern science. No doubt the Church had preached the philosophy of kindliness and service to fellow-men and some of the better kings had tried to give practical effect to these doctrines (altruistic philosophy), but I think it was not possible to achieve much for the simple reason that technical methods of production known in the earlier ages were too inefficient to produce plenty for all.

The advanced states of Europe and the U.S.A. began to move out of these dreadful medieval conditions during the seventies of the last century, when modern science began to develop and new methods of production were applied in mass-scale. As a result of a century of progress, individual conditions of living and public health have steadily improved in Britain and in many other countries of Europe, and America. Probably the best index is afforded by the average life, which has increased from 29 about a hundred and fifty years ago to 58 in the U.K. and to 63 in the U.S.A., according to reliable reports. Not satisfied with that, you are having a social insurance measure which will take care of the man 'from the cradle to the grave.' We can say that as far as individual life is concerned, science has achieved the target aimed at by the great leaders of the world, and if it has not done so in your country, it is on a fair way to the goal.

Let us come to my own country, India. I have given you certain figures, and you can see that the energy-index in my country per man is not more than 100 units, or it may be at most 120 units. The energy-index is thus seen in India to be twenty to thirty times smaller than in England. The average income of an Indian has been estimated at 65 rupees, only £5 per year. This is about thirty times smaller than in your country. The reason is plain enough. India has been almost entirely untouched by modern scientific methods, and the great task before us is the application of modern scientific and industrial methods for development of India's potential wealth if we wish to pass out of the present dreadful conditions. Some months ago you sent a distinguished ambassador of science, Professor A. V. Hill, to my country, and he took pains, as no other man had done before, to study at first hand the conditions in India, and he has taken no pains to hide his findings. These are practically the same as mine. By whatever standards you measure, you find we are still in the Middle Ages. The thin coating of modernism which travellers find in the great cities of Bombay, Calcutta, and Delhi, must not lead you astray. Ninety per cent. of India is still in the sixteenth-century conditions of England. We have terrible child mortality, the conditions of public health are terrible, and 90 per cent. of the men have to live in slums; the average life is not more than 27. The mass of the people have hardly any interest in life, and we are on the brink of disaster, as Professor Hill has told us.

We have to understand the problem properly, and attempts are being made in India to do so. Many post-war planning committees have been set up by the Government, but their pronouncements have only added to the general confusion. Some advocate road building without trying to find out who are the men who will use the roads, and for what purpose and by what conveyance; some advocate agriculture, others think there is an inherent antagonism between agriculture and industrialisation; but the common man only sees that the terms of superannuated officers are extended on higher salaries. Probably the planners lack direction from the centre which is not yet forthcoming.

It is obvious that the clearest way to define the objective would be to declare that India's *per capita* income should be progressively increased to modern figures compatible with her resources, and as a necessary first step, India's energy-index should be progressively increased to the figures attained in all modern countries. Let us put a definite target, say 100 units within the next ten years, and we shall also have to use this energy suitably. This is not a large figure, for even pre-war Mexico used to produce 180 units of energy per head, and we produce only 9 units. Such a declaration, if it is forthcoming, would convince the people of India of the Government's bona fides, as nothing else would do, and the Government would have to set up proper machinery for producing electrical energy within the next ten years, and to find a use for the energy for the benefit of India's masses. Let us look at this figure from another angle. It is slightly larger than the pre-war production of electrical energy in the U.K., and according to a P.E.P. report nearly £600,000,000 was invested in the electrical industries in the U.K. Probably a comparable amount will be needed in India, but if the undertakings are properly planned, many of the mistakes committed in the past can be avoided, and a smaller sum may be sufficient. It will also greatly promote trade-relations between India and the United Kingdom, for India will have to depend for some time yet to come on imported machinery for her development.

Now, the electrification of India will necessarily need that we spend most of this energy in industrialisation. But it does not mean that we shall neglect agriculture, As a matter of fact, the present position of agriculture has been entirely misunderstood. At the present time, according to the 1931 census, near 85 per cent. of India's population lives on the country, and anybody having the least knowledge of economics will tell us that the country cannot afford to have a decent standard of living unless a large percentage of the population is taken from the land. When industrial revolution began in your country your rural population was sucked into the industrial centres. In our

country the process was in the opposite direction. As factory-made, cheap goods began to be exported to India, the artisan classes gradually lost their profession. The weavers, the potters, the blacksmiths, and artisans of almost all classes lost their jobs, and they became peasants, and the small amount of industrialisation which had taken place in India subsequently has been insufficient to restore the balance. If we have to raise the standard of living for the common man in our country we must take away a large percentage of them from the country back to the towns, and must provide work for them by creating more industries. Even in spite of the great number of men in agriculture, are we self-sufficient as regards food production? The terrible Bengal famine of course was due to many causes, but we have no margin of safety in food matters. A survey of the productivity of Indian soil shows that an acre in India produces four times less of crops than in other countries. This is due to the fact that we have been taking—on account of over-population—too much from the land, without putting anything back, or allowing the soil to recoup. Indian soil is deficient in nitrogen, in phosphorus, in potash, and according to Dr. Burns, if we have to increase our production by 20 per cent., we require 6,000,000 tons of ammonia sulphate or some other nitrogen fertiliser containing equal amount of nitrogen, and the amount which we require in phosphate fertilisers has not yet been calculated. But why do not we take fertilisers from other countries? It would not be economic. Fertilisers used to be exported to India at a fairly high price, but owing to a poor system of distribution, they reached the peasant at double the landing price, and the peasant did not find it profitable to use fertilisers. For the fertiliser industries we require electrification, and we can easily consume 10,000 to 20,000 million units on a fertiliser industry alone. That is another aspect; the peasant wants money crops, and unless he has a corresponding industry it is no good raising cotton or sugar as money crops. These arguments show that if we want to raise the standard of living in India, if we want India to step out of medieval times, we must have a thorough planned scheme like the Russian Five Year Plan or the Democratic Swedish Plan in which the interests of industry and agriculture have been worked in a coherent system. Probably the problems of agriculture can be solved, as in America, by totalitarian regional planning, and we can develop simultaneously not only industry but also reclaim our soil and provide employment for millions. I have shown that the hinterland of Calcutta, which about 100 years ago was one of the healthiest and most productive places in the whole world, has been ruined by mishandling, but can be revived by using the same methods developed with such signal success in the Tennessee Valley.

I have given you a cursory survey of the problems of India and the way in which we have to look at it. The Indian leaders have so far paid attention only to the question of political freedom—of course every one of us wants that India should attain to full nationhood and the people have full sovereignty, but the problem of living for millions of Indians has been entirely neglected, and we believe that the only way to achieve unity of thought and purpose in the political world is to look first at the problem of living for India's millions. To get all this done there must be a national purpose, and I do not see how any planning can be done without a national Government, or unless we have a Government which has popular support and is manned by leaders in whom the people have confidence. I must say that this is not only my view but that of many of us, particularly of the group of Indian scientists responsible for the publication of the journal *Science and Culture*; and three of our editors are here and three other members who, though they are not editors, are connected with the paper through editorial collaboration. That is how we try to undertsand the heart of the problem in India. There are psychological, political and other problems to which we have not probably given serious attention, but we are convinced that if we want to solve any problem we, as scientists, know we must collect the various facts in an objective way and try to understand them by methods of analysis: then and then only we can find out an integrated solution.

Sir Jnan Chandra Ghosh

For the past ten years in the columns of the journal *Science and Culture* we in India have promulgated the view that political freedom is not an end in itself. That freedom, if it is to bring happiness to the millions of our countrymen, has to be supplemented by economic development, and such economic development is not possible if we stick to the old ways of production. Some of us feel that crude methods of production, even though they may be necessary as an interim measure, will not supply our wants and will not give us the standards of living which we all desire in this continent of India. We cannot afford to have deficient methods of production simply for the purpose of employing more people in any particular occupation, though at a very much lower level. It is essential that whatever be the means we employ the quantities of goods that we should produce in India should be very much more than they are at present. The income of an average Indian being 65 rupees per year, obviously people here accustomed to other standards of living

cannot easily imagine them on that basis. We can live only as a half-starved nation. That is the great and fundamental problem that has got to be solved. Scientists and industrialists in other parts of the world are convinced of the fact that modern methods should be applied to production, and that suitable systems of distribution should be employed. Everyone in this world can have a fuller and more satisfying life ; but difficulties such as those arising from vested interests are created by people who have not, like those of scientists, a pure objective mentality. We men of science, when confronted with a problem, try to find out exactly what the facts of the case are, analyse them, reject those things which are irrelevant, keep an open mind, suspend judgement until all the facts of the case have been realised, and then prescribe a solution independent of whether it is antagonistic to existing views or not. That is the type of mentality which should be created in India. If that is done we feel there is a great future internationally not only for our country but for the whole of civilisation.

It is in that spirit that we preach the gospel of our science to our countrymen. Our countrymen think the powers of humanity are much lower than the powers of nature, and that it is not difficult to understand when catastrophes such as cyclones, floods, and famine occur on such a vast scale. It is possible, however, if the human mind is applied to the problems of environment, to master this struggle against fate by energies directed towards other and better ways of living. We hope that we carry with us the goodwill of you all in the discussions that await us in the solution of our difficulties.

Prof. S. K. Mitra

Professor Saha has said that in India there is now all sorts of planning, and I have always said that piecemeal planning leads us nowhere. As an illustration : in India we have mass illiteracy ; and I am asked, why not use broadcasting to combat that ? I have been putting forward that proposal for a very long time, but in order to use broadcasting for mass education you require, in the first place, big and efficient transmitting stations and good programmes ; but even if we have those, they are useless unless receivers are distributed over the whole country. Now the first difficulty in working the receiver is that in the villages we have no electricity. So ultimately we come to the need for electrical development, which must go hand-in-hand with our attempts to utilise products. That shows the sort of interrelation there is between developments in different aspects. We have our famous scheme for educational programmes over forty years. We are all glad that at last something has been done ; but if 90 per cent. of the population are illiterate, how are we going to give education to them ? We must provide books for them, for providing books we require paper, for that we require a huge paper industry, and for a paper industry a chemical industry, and for those industries we require cheap power. Why, when we cross the Mediterranean from Tunisia, do we find people better fed, clothed, and educated ? The simple answer is that besides men and animals these people have harnessed natural power to work for them. In *Science and Culture* we find that every Englishman has six or seven mechanical slaves working for him, and what do those slaves do ? They produce commodities, help in their distribution, and provide comforts ; and naturally, if I have six slaves, I am enjoying much more comfort than somebody else who has not ; but there is only one slave in India for about seven persons. Whatever way we look at the problem it comes to development of cheap power, and this power should be made to produce goods, produce commodities, and help in their distribution. Here in England there are different political views about the distribution of wealth, and so your problem will be after the war how to ensure more equitable distribution of wealth, but our problem in India is very much more difficult : we have first to create more wealth and then see that that wealth is equitably distributed. And the starting point of this task is the development of cheap power.

Sir Shanti S. Bhatnagar, F.R.S.

In a lecture which I delivered before the Eastern Association I advocated somewhat similar ideas to those which Professor Saha has advanced to-day. As a matter of fact, in the post-war programme of development there is only one point which seems to have been quite satisfactorily understood : that power is the first important factor to which we must devote our attention. India is capable of producing a large amount of power from her water resources, and there are notable examples of its use, as in the Punjab, where a very large irrigated area has yielded funds which have been applied through a trust to the benefit of the community.

If we wish for peace and amity in the world, the world must feel that there are resources available to afford such comforts everywhere as are enjoyed in the developed countries ; and in achieving this science will play a very important part.

The Council of Scientific and Industrial Research in India was established with very inadequate funds at their disposal ; we have been clamorous for more money, and recently there have been further grants, and even industry has come to our aid because it is realised that without developing industries and agriculture it is impossible to keep the peace in the country. These are good signs, and we hope that in these attempts, with science asserting itself in India, we shall have the blessings of this country.

Sir Richard Gregory, Bt., F.R.S.

Before our attention was given to fundamental scientific research or industrial research in India there was one far-seeing organisation, the Indian Cotton Committee, which had been carrying out most valuable research on these lines for industrial development in that country. Dr. Nazir Ahmad is here among the delegates, and I think you would appreciate a few words from him.

Dr. Nazir Ahmad

The textile industry in India is one of the few industries which has developed during the last hundred years. India is the largest cotton-growing country in the British Empire, and the second largest cotton-growing country in the world. It has a very large textile industry, which amounts nowadays to something like 9,000,000 spindles,

and employs nearly 400,000 men in its various mills. Apart from that there are a large number of people who are engaged in the hand loom industry. But in spite of the fact that these figures sound large, the consumption of cloth in India has remained at a very low level. It has for many years remained about 16 yards per head of the population per year, and when you think of the entire need of a person for over a whole year, you will realise that 16 yards of cloth is not very much.

This represents to me in a symbolic way the amount of money that is spent upon scientific research in India. I make this digression from cotton textiles to scientific research, because one of the things which has impressed me very greatly since my arrival in this country is the manner in which money is being spent both by the Government and by trade and industry on the development of scientific research, especially scientific research applied to industry. I have been visiting institutions which are maintained either partly, or even wholly at times, by the respective trades and industries, and I realise how, by spending money on their own special problems, they have been able to improve the quality of their goods and thus to render a great service not only to pure science, but also to society as a whole. Only this morning, for instance, I visited the British Laundry Association's laboratory, and perhaps you might be surprised to hear that the amount that that laboratory spent on itself, which represents only a very small sideline of the textile industry, is the amount which in India I spent on my entire laboratory. That is one feature to which I would like to draw your attention, that at present the amount of money which is being spent on scientific research in India is ridiculously small: if more were made available, I do not doubt that there would be found sufficient talent and ability in India to make full use of it and render a good account of it.

Sir Richard Gregory has referred to the work of the Indian Central Cotton Committee. That is an example of what can be done if money is made available. During the last 25 years or so that this Cotton Committee has been in existence, with very small sums compared to what is spent here, it has been instrumental in evolving new strains of cotton which have given better clothes to the Indian people at large. It has not only been instrumental in evolving new strains of cotton: it has also carried out researches on improving the methods of manufacture, which have been taken up by some of the Indian mills, but there again the difficulty has been that in many cases when we have the results of the research we have not the means of making full use of them—the liaison side has been neglected, not because the realisation has not been there, but because the means have not been there.

I would, therefore, particularly like to impress this point upon you: I believe here there is an idea that at least 1 per cent. of income should be spent upon research—I can say we shall be well satisfied if we are able to spend one-half of 1 per cent. of income on scientific research in India.

Prof. J. N. Mukherjee

One point that perhaps has not received attention so far is this: supposing the scientists can plan, can take an objective attitude, can set up their targets, can define a programme, the question is how to get done what should be done. There comes the question of relations between science and scientists and the administration and society in general. Our difficulties will be perhaps more in that sphere. We have a large number of committees of reconstruction both at the centre and in the provinces. They will surely work out certain plans, and they will surely also try to co-ordinate them. But the danger is that without a detached objective we may soon be unable to see the view because of the trees, and it is in this sphere, I think, that our friends here can help us most. H.M. Government and the British people can, I am sure, help us a good deal in giving directive purpose to our endeavours. It has been a great pleasure to us to find that we can count on that support. I shall refer to one aspect in the way of illustration. We have the same structure as most of the advanced countries: we have Departments of Culture, of Public Health, of Irrigation, of Forestry, and so on, but have we been able to achieve the result that we could have got if even our limited resources in men and money were fully utilised? Perhaps the answer will be in the negative, and therefore in the future we hope there will be an assurance that the plans which scientists may draw up and the financial support that may be given will be utilised to the best advantage. The reason why I am emphasising this is that unless we can get a plan worked out with the target to be achieved in each line in a limited number of years, then the development may be lop-sided and we may fall short of our goal. The question is not of agriculture versus industry, of communications versus public health, of development of power versus the chemical industry, and so on; the question is one of a co-ordinated plan in which all inter-relationships have been visualised and co-ordinated.

Sir Richard Gregory, Bt., F.R.S.

We have listened with great attention to what has been said about certain problems in India which concern all of us at the present time, and have been expressed so eloquently by our colleagues. It is fortunate for us to be able to have such statements in a perfectly free atmosphere, without any political or other consideration, from representatives of science in India. As President of the British Association I am grateful to our colleagues from India who have put forward so well the position and the social and industrial needs objectively in such an impressive way.

At this, the first meeting of its kind in this hall, a number of distinguished scientists from India have shown their knowledge and interest in the human side, which is usually disassociated from the scientific laboratory. But they are both scientists and human beings with human aspirations, and that could not have been better expressed than it has been this afternoon. On behalf of the Association, and of this meeting, I express our very grateful acknowledgment of the impetus that they have given to the prime object of our Division for the Social and International Relations of Science, and I hope it will bear fruit in the increase of energy for human progress in their country.

THE PLACE OF SCIENCE IN INDUSTRY

TRANSACTIONS OF A CONFERENCE HELD BY THE DIVISION FOR THE SOCIAL AND INTERNATIONAL RELATIONS OF SCIENCE, JANUARY 12–13, 1945

EARLY in 1944 arrangements were in hand for a conference on the Place of Science in Industry, when circumstances arose which temporarily made it impossible for the Association (like other organisations) to continue such activities. As soon, however, as it became possible again, arrangements for this conference were resumed, and it was held on Friday and Saturday, January 12 to 13, 1945, in the theatre of the Royal Institution, Albemarle Street, London, by kind permission of the Managers of the Institution.

WHAT INDUSTRY OWES TO SCIENCE

FRIDAY, JANUARY 12, 1945 : MORNING SESSION

OPENING BY SIR RICHARD GREGORY, BT., F.R.S., PRESIDENT OF THE ASSOCIATION

THIS is the opening Session of a two-days' Conference on The Place of Science in Industry, at which prominent aspects of scientific research and industrial development will be presented with high authority. Much attention has been given to this subject lately and valuable reports upon existing conditions and future possibilities have been published by the Federation of British Industries, the Parliamentary and Scientific Committee, and other bodies. In addition, a well-considered statement has been issued by Nuffield College, Oxford, as the result of conferences attended by leading representatives of industry and the natural sciences, as well as of social and economic research, which is the College's particular field.

As one of the prime objects of the British Association is to promote general interest in science and its applications, these recent pronouncements relating to the significance of research and its social repercussions can have their purposes advanced by public conferences of this kind. Since its foundation more than a century ago the Association has devoted the main part of the proceeds of every annual meeting in Great Britain and overseas to assist scientific research in many directions. This has been done with the single aim of advancing natural knowledge, though the results have often lead to the creation and development of large industries. The day is passed, however, when a distinction was made between the pursuit of scientific truth for its own sake and research carried on with practical or profitable motives in mind. All endeavours to discover facts relating to natural things and forces belong to scientific research, whether investigations operate in academic laboratories or in industrial works. It is no longer possible or desirable to separate pure and applied research workers into teams of 'Gentlemen' *versus* 'Players' in the sense in which these words are commonly used.

It is equally undesirable to separate scientists from other citizens in their social duties and responsibilities. The ultimate effect of a scientific or technical discovery cannot be predicted either from the point of view of human welfare or that of warfare. The common fatty oil called glycerin, which has now many uses, was known sixty years before studies of its constitution led to the incidental discovery of the highly explosive compound, nitro-glycerin, a century ago. It remained merely an interesting chemical preparation until about fifteen years later when Nobel found that dynamite, gelignite and similar explosives could be manufactured by mixing it with certain absorbent substances. These explosives are widely used in mining and for blasting purposes of engineering, and at no stage in their development has there been any scientific or other authority which could prohibit their industrial production throughout the world.

This Conference, however, is not concerned with the control of mechanical inventions or violent natural powers arising out of scientific enquiry, whether they are employed in the constructive arts of peace or manufactured as weapons of war. The intentions are rather to show that we have the capacity to combine science with practice in industrial development and that increased contacts between them will insure the advancement of both. There must be a two-way traffic between

scientists and industrialists if we are to be in the van of progressive life and service. Advances made on this united front will raise standards of living and strengthen the social structure if they are correlated with humanistic national policy. Public feeling will not now tolerate the deplorable social effects of the introduction of new powers and processes of a century and more ago. In the early days of the industrial revolution in this country, the discoveries of science were used with as much indifference to science as to humanity. The inventions of the eighteenth and early nineteenth centuries came from the workshop rather than from the scientific laboratory, which has since become their prime source.

The Royal Institution, in whose historic lecture room we have the privilege to meet, has been the place of a number of fundamental discoveries upon which vast industrial structures have been erected. It was in the laboratories of this Institution that Michael Faraday discovered the principle of magneto-electricity upon which the construction of every electric dynamo is based. He and all other distinguished workers who have succeeded him were engaged in purely scientific investigations upon which great industries providing employment for millions of people have been founded. As one of the functions of the Institution is to diffuse scientific knowledge as well as to increase it by experiment, there is no place in the world where a Conference on The Place of Science in Industry could be held more appropriately than in this lecture room.

On account also of the intimate relationships between new and changing industrial operations with labour and employment problems, it is particularly gratifying that my esteemed friend, Mr. Ernest Bevin, is able to preside at this opening session. When he was President of the Trades Union Congress in 1937, he paid tribute in his address to the progress made in scientific fields and pointed out that society had not kept pace with it by making the fundamental re-adjustments needed to assimilate the results of research, discovery and invention. Awareness of this lag between scientific knowledge and social wisdom is now widespread, but we have yet far to go before a closer approach is achieved. In the future, as a result of conferences of this kind we shall see less of a lag between discovery and its application in the development of our industries through closer contact between work done in the laboratory and its service to our industries. In asking Mr. Bevin to address this Conference I can assure him that in this and other directions science has a message to deliver and a mission to perform with higher aims than those usually associated with it in the public mind.

Address by the
Rt. Hon. Ernest Bevin, P.C., M.P.
Chairman at the opening of the Session

IT was with considerable pleasure that I responded to the invitation of Sir Richard Gregory to preside at this Conference to-day. There are two reasons why I should have had great difficulty in refusing a request from him. First we both have the advantage of being Bristolians ; secondly, in my very young days, I was closely associated with his father on the Bristol Trades Council. I have very pleasant recollections of the talks we had on the way home late in the evenings, and the influence his father brought to bear on many of us youngsters in those days, which have influenced our outlook on life since.

This conference is called to hear papers read, and to discuss the place of science in industry. I think it is true to say that science has not merely a place in industry, but does in fact dominate it now. There is no doubt that the great scientific developments of the century have influenced not only the whole of our standard of living, but indeed our entire conception of life. The speed of scientific development is sometimes a little embarrassing, often involving rapid adaptations on the part of both industry and the workers, and necessitating capital development and new training at a rate which it is difficult to appreciate without having had experience of them. On the other hand after industry has been adapted to meet the needs of scientific progress and the productive side has been developed, it is a long time before the advantages which science can give are able to find their way into the universal life of our people. Our economic structure is not simple, and changes in one direction involve changes in many others, if we are to derive the full benefit from the adoption of new scientific principles. The pioneer work of that great scientist Faraday ought by now to have resulted in all our cities and homes being well-lit, providing a beautiful environment, but notwithstanding all the years that have gone, and all the knowledge that has been acquired, that is still a dream of the future.

The difficulties that have been encountered in applying science in the home are first that the structure and size and lay-out of the homes do not change fast enough for new ideas and new devices to be introduced. You have a dead weight, a hampering economic pull against change, fastened into the body politic generally. The other difficulty is that manufacturing and distributive costs have not been low enough to bring modern appliances within the means of our ordinary people. The lighting of our homes and factories to-day leaves much to be desired. The monopoly price of such things as lamps,

enabling enormous profits to be made out of an industry like that, has, I am quite certain, retarded what should have been a normal development of a discovery like Faraday's work.

When these changes are due to take place they are often throttled by a whole series of monopolistic tendencies, cumbersome protective patent laws, which were intended to protect inventors but have now become more hampering even than tariffs, and even between nations far more restrictive in their practices. In consequence many things which would have been of great advantage to humanity are often stillborn.

It is quite clear that more and more money and even greater effort must be devoted to research and to development. At the same time, and concurrently with it, it will be for the States of the world to find a way to make the results flow very rapidly to the masses of the people. It must be recognized that the economic system has to be scientifically adjusted to enable new scientific discoveries to become more and more available to the ordinary people. This is the biggest obstacle that must be surmounted if the workers are to derive full benefit from these scientific developments, and indeed welcome them.

It would be interesting for a study to be made to find out what period of time elapses between the date of a new discovery or invention and the development of the manufacturing capacity for its production in commercial form, and to compare it with the time it takes for the new products and benefits to become available for the ordinary people of the country.

Industry must become more receptive to scientific progress and be induced to accelerate development, particularly in peace time, and to distribute it at a speed we have achieved during the war. Under the stress and strain of battling with the enemy, the speed at which new discoveries have been developed for general use has been amazing, but in peace time this period of development is long drawn out. The worker becomes therefore apprehensive about the introduction of new scientific principles which, during their period of development in industry, may cause temporary upset to all his habits and mode of life, without any prospect that he himself will be able to benefit quickly from the advantages of the new discovery. It has been my experience that when new discoveries have to be introduced into an industry, if I could have said to the men : 'As soon as you get this or that produced, and make other changes, you yourselves are going to benefit from this in your daily life,' then my task would have been much easier, but the principle of passing on the results of discovery seems always to the ordinary man a long way off. This state of affairs is due in the main to the wrong conception of the directors of industry, hampered by the tradition of the past. It is cumbersome and out of date, and if I may put in a word for the Civil Service, far more bureaucratic than they know how to be.

I would plead for a scientific study of the problem how best to bring the benefits of scientific discovery into the lives of the people, so that they can be enjoyed by the masses as quickly as possible, and at a price within their reach. I think it is obvious we could and should bear the cost of the development of scientific discoveries. If they can result in a new industry being established, which results in an improvement in the standard of life, a reduction of sickness, or the dangers of maternal mortality, then they contribute to the health and happiness of the people.

Sir Richard Gregory has reminded me that I tried some years ago to bring the Trade Unions Congress and the British Association together. One of the objects I had in mind was to stimulate the interest of the workers in scientific progress. If I may put it another way, I wanted to get the benefits of the advances of science made available quickly to the people, so they would have a vested interest, as it were, in scientific discovery. The masses would then show a keen interest in the work of scientists, be receptive to new ideas and welcome scientific progress. I still hope for that, but I repeat it is the experience of what has been done in war-time, and the speed at which progress can be made, which fills me with hope that the obstacles to rapid progress in peace-time can be overcome, and the great benefits which science can offer be made to flow quickly into the daily lives of our people. The progress we have made in the previous centuries may appear infinitesimal, in comparison with what we can do in the future to brighten the lives of the great masses of the people throughout the world.

Rt. Hon. Lord Brabazon of Tara, P.C.

Aviation

GREAT industries are, and have been, founded on fundamental research, and some of the discoveries of fundamental research have been made by accident. Röntgen, by accident, became aware of the fluorescence of a screen near him when he was making experiments with an exhausted vacuum tube. That led to the discovery of X-rays. Becquerel, by accident, left cases of dry plates within range of the effects of pitchblende. That led to the investigation and development of our knowledge of radio-activity. Faraday was the man to whom we owe our great electrical industry. It may be doubted whether Faraday understood the conclusions which Clerk Maxwell brought out

from his work. You cannot tell where fundamental research will lead. The work of Crookes and J. J. Thomson culminated in the electron. It was a philosophical conception and no one could know that it was going to lead to radio development. These are examples of fundamental research leading accidentally to great developments in other walks of life.

There was a time when a physicist could achieve new results with simple apparatus. I believe that those days are gone, and that physics to-day demand most expensive apparatus. No laboratory is complete without a cyclotron. Consequently we are moving in fundamental physics from the private investigation towards State maintenance. I do not see who is to provide this expensive equipment if it is not the State, and if it is not provided, we cannot compete with other nations who equip their laboratories in that way. But those who work in laboratories on fundamental research must be allowed to do what they like, regardless of what practical value appears to be attached to their work. And here arises a difficulty. If the State provides equipment, the State may try to dictate what is to be done with it. But was there ever a greater mistake than to dictate to people who are doing fundamental research and say what they are to do. In that case, incidentally, it is not fundamental but *ad hoc* research and the two are not the same.

Curiously enough, flight was not born from the laboratory. In fact scientific opinion had a painful effect upon early views as to the possibility of flight. Lord Kelvin laid it down that dynamic flight was an impossibility, and his influence was such that professional scientists generally,[1] at that time classed flight with the philosopher's stone or perpetual motion. The old adage, 'Pigs might fly' was applicable; and incidentally I am an historical character because I took the first pig up in the air to fly.

Maxim and Langley approached this problem purely from the scientific point of view. Maxim did some very good work upon flight investigation; but there were others who approached it from a practical point of view, like Lilienthal and Pilcher. Two of these practical people sacrificed their lives to their investigations. But it was left to the Wright brothers to succeed right at the beginning, and it is interesting for us to consider what sort of men they were. They were the sort of men who to-day keep a bicycle shop, and sell gramophones in the provinces. They were practical, with great knowledge of mechanics and a certain amount of scientific background and great initiative. They seem to me to have possessed everything that a scientist should possess. They tested everything and approached the problem in a correct manner. They had a small wind tunnel and made tests for drag and stress and structure, and built their own aero engines—a very remarkable feat—and they studied all the available data. Few people realised here that there was a contest in progress. There was Langley, the great scientist, with all the resources of the United States behind him, on the one side, and there was the bicycle-maker on the other. I do not think any of us appreciate how near was the race between those two. Nobody knows whether the Langley machine would have flown or not. It certainly had the possibility, but its failure had nothing to do with the aero-dynamic side, but was due to bad launching, which twice tipped the machine so that it fell into the Potomac River. The second occasion of its accident was on December 8, 1903, and it was on December 17 of 1903 that the Wrights made their first flight. It was a very close race.

Just as Clerk Maxwell laid down the scientific interpretation of electro-magnetism, so Lanchester enunciated in 1897 the scientific aspect of flight, and I think we have never been fair to Lanchester, who deserved much honour he did not receive.

There is no doubt that the aeroplane has advanced various sciences in various directions. The world of science has replied by making the aeroplane better and better. For instance, there is the matter of light alloys, combining strength with lightness; and a tremendous drive has taken place to meet the demands of modern engines and aeroplane construction. When we look at an aero engine now, we may ask ourselves why such an engine could not have been made twenty years ago. The answer is that metallurgical advances during that time have made it possible.

Take another science: meteorology. No science deserves more study to-day, and there must be room for great discoveries in it. A great deal has been done during this war. When with jet propelled aeroplanes we have to travel 40,000 feet up, there is an enormous amount we want to know. We know very little about the upper currents of the air, but from the point of view of commercial aviation and long-distance flying we want to know more and more. At present the greatest danger in flight is the threat of icing; it is being countered by various devices on the aeroplane, but the soundest way is to keep away from the conditions. All we know at present is that at over 25,000 feet with the temperature under −12° C. we are comparatively free from the trouble.

High octane fuel has been developed for high take-off power in aeroplanes and has had its repercussion on the internal combustion engine generally. The development of plastics is advancing with a rush through the greedy demand of the aeroplane. Radar, now an advanced science, was almost created by its suitability for aeroplane detection. The inventor of that apparatus was as much responsible for victory in the battle of Britain as any aeroplane pilot, if not more.

We have all dreamt and hoped that the reciprocating engine would be replaced by the gas turbine. Well, Whittle, with his jet, has shown the way. The advent of the jet has changed the whole outlook of flight fundamentally. On the side of civil aviation the economic cruising speed, by virtue of that invention, will change from 200 to 400 m.p.h., and we shall be able, when we get proper pressurisation, to fly at heights never dreamt of before. And the gas turbine opens up vistas of employment in various walks of life. The motor car driven by gas turbine is a practical proposition to-day, and would be upon the road if we were not all concentrating upon the war effort.

This is one of the most important periods in the history of flight. Never was a time when we were

[1] The interest of Lord Rayleigh, on the other hand, was referred to later in the course of discussion.

more in need of science to back us up and, particularly from the point of view of fundamental research in aeronautics. Here, again, the equipment is very expensive and involves very great expenditure. The organisation, directed no doubt by the Aeronautical Research Board, must be closely tied up with our universities and industries. But the expenditure can only be borne by the State. When we are dealing with sonic and supersonic speeds, wind tunnels are very expensive. It is the State alone which can afford them. But it would be well worth the expenditure because as the science of flight advances, so will many other industries benefit; and also the future of this country will be affected. We are going to be judged very much throughout the world by what we do in flying.

Prof. Southwell has truly said, 'Aeronautics is ordinary engineering made more difficult.' It is indeed much more difficult, and it needs all the scientific help it can get. In this heterogenous complexity of advanced technique in new sciences, moves the designer, expected to be an encyclopædia of knowledge and a cornucopia of originality. The designer has served us nobly. He has gone ahead all along the line and produced a remarkable war machine. I do not know whether you call him a technician or a scientist. All I do know is that he wants all the help he can get from science.

The Chairman
Rt. Hon. Ernest Bevin, P.C., M.P.

As I have to go in a few minutes there is only one comment I want to make on that remarkable speech for which we are indebted to Lord Brabazon. It is this: my experience in the war has been that science has stopped in the field he mentioned a little short. That is to say the application part of it is not as close up to the scientific discovery as it ought to be. That was the case for example with radar alone, in which, as he rightly says, we were in advance, so that it had such a remarkable effect in the Battle of Britain. When I took office, you will agree with me, we had practically no radio mechanics in the country in any number and I had to try to get trained in one year no fewer than 70,000 special radio mechanics. All I would plead is for this question of the application and training of the next stage, in order to apply it normally. It has a bearing on what I said in my opening remarks. For instance there were only 14,000 draftsmen in the whole of this country when I took office, not as many as are employed at one undertaking in America, and the need to train engineers and draftsmen in modernised methods to meet a tremendous development is an extremely difficult one indeed. If money has to be spent on science, and I quite agree with what he says, I hope that narrow limitation on what I might call the laboratory line of demarcation will not be tolerated, but that it will get nearer to industry, so that industry can march in step with all the people who have to be trained. I have seen the terrible handicap in this war due to industry not knowing where science is really carrying them. But it has come as a great shock to them afterwards.

(The chair was taken for the remainder of the session by Sir Richard Gregory, Bt., F.R.S.)

Sir Robert Watson Watt, F.R.S.

Telecommunications

It would be ungracious were the three batsmen of this innings to fail in expressing their thanks to the organisers of the Conference, who have put them in on the easiest of wickets. Lord Brabazon, Dr. Astbury and I might well, if we were not assured of your good-natured tolerance in listening to more than one sentence from each of us, have said no more than this—'the industry of which I speak owes its very existence to formal science.' Perhaps more assuredly than any of the three I could go on to say 'indeed my industry was founded on the direct and deliberate application of contemporary academic science.' I should then find myself inevitably involved—as indeed I shall in any case find myself involved—in some attempt to define what I mean by science with various qualifying adjectives. But having admitted the foundation fact, the cynic will reply that, so far as he can judge, the industry owes to science two things other than its foundation. One a succession of staggering crises giving rise to the half-justified complaint 'science is what makes securities insecure'; and second, a series of *post-facto* explanations (often very much in arrear) of achieved successes and established failures. And if the cynic is also a pessimist, he will go on to say that some of the triumphs of the industry have been achieved only by calculated disregard of the voice of science.

A catalogue of the main applications of science in the historic development of telecommunications is in itself an almost sufficient illustration of the meaning, though not a justification, of the first charge. Line telegraphy was just getting itself established when its future was temporarily obscured by the emergence of line telephony from its purely scientific foundation in 1837 through the still primarily academic experiment of Reis in 1861 to the 'experiment-for-application' of Graham Bell in 1876. The equilibrium of the cable telegraph world, which owes so much to science in the person of William Thomson Lord Kelvin was shaken by the advent of long-wave wireless telegraphy and just escaped being completely upset by the advent of short-wave wireless telegraphy. That all these five branches of telecommunications, supplemented by the newer branches of radio telephony, of broadcasting, of radio aids to navigation, of facsimile transmission, of television, and of radar, continue to flourish side by side suggests that a scientifically founded industry can, with advantage, exchange new securities for old, and that the advent of the long-distance submarine telephone cable is no more likely to be a Greek gift from science than were its predecessors.

The second charge, that science in the experimental laboratory and in the study armchair contributes explanations in arrear of a mechanism which has already been tested in application, is well founded, but is far from being a damaging charge. I propose to devote more attention to it after looking at the third of the propositions of the cynic.

The two classical examples in telecommunications of a disservice to industrial progress rendered by men of science are the comments of Sir George

Gabriel Stokes on phenomena observed by David Hughes here in London, and the frequently quoted statement by Marconi that he achieved his trans-Atlantic signalling against the best available scientific advice, which promised him certain failure. Both examples are valid condemnations not of science but of scientists. In his summary dismissal of those observations which anticipated Heinrich Hertz, Stokes was guilty of a superficial pontification which descends all too easily on the elder statesmen of science. The incident is a terrible warning which is less needed by officials of the Royal Society of the present day than it was by some of their predecessors. The pseudo-scientific advice which was disregarded by Marconi when he spanned the Atlantic was not scientific if it did not qualify its statement of limitations with an appropriate list of the hypotheses on which the statement was based. There was already scientific evidence, formulated into a working hypothesis by Balfour Stewart, which would have been brought into a fully scientific examination. Both examples are regrettably human examples of scientists who ceased temporarily to be wholly scientific.

It would be useful to draw a distinction in any discussion on science in industry between what may roughly be called internal science and external science, the former comprising all the scientific effort which is oriented towards the direct solution, within the parent technique of the industry, of problems peculiar to the industry. On the radio side of telecommunications this internal science concerns itself with the generation, radiation, propagation, reception and display of the radio signals conveying that intelligence which is the merchandise carried by the telecommunications industry acting as a transport agency. It is within this field of internal science that one finds scope for the second charge by the cynic. But, as I have suggested, the activity thus cynically represented is, in fact, a highly beneficent and instructive activity. Science in its application to industry is not merely theoretical science, it is not merely the science of fundamental experiment, nor is it solely a marriage of these two aspects of what I have already crudely called formal science. Many of the most useful applications of science to industry come from a rather diffuse empiricism, a trying out of a large number of reasonable variations in ingredients or conditions of use. The *ex post facto* intervention of hypotheses developed from experiment is invaluable in reducing the range of unpromising variations attempted. It confines this necessary empiricism of applied science within the limits of oriented and canalised empiricism. There is, to put the matter bluntly, a conflict between æsthetics and economics in the applications of science to industry, and elegance can only be served within limits set by economics. In my own radio work I have occasionally tried to express this difficulty by saying that mathematics are, in general, dearer than motor-vans, but cheaper than aeroplanes; that is, that quick experiments on the ground may give a sufficiently good answer, at less cost, than a full theoretical investigation, but that it may be economically desirable to do a good deal of theoretical work in preference to much work in a flying laboratory.

Perhaps one can summarise the interplay of formal science and that oriented empiricism which still falls within the limits of the scientific method by saying, in the military jargon of the day, that formal science by theory and experiment opens a bridgehead on the industrial front; that the bridgehead is enlarged by the oriented empiricism of good technical practice; and that the gains are consolidated by further applications of formal science.

It is scarcely necessary to deal at any greater length with the part played by internal science in the telecommunications industry. That part has been a very great one, but it is reasonably familiar and includes a very general application of that essential science which I prefer to regard not merely as a body of ordered facts, not merely as a system of temporarily valuable hypotheses, but as an attitude of mind. This attitude of mind conditions all the activities which a moment or so ago I so lightly dismissed as 'good technical practice,' the scientific control of process, the scientific suggestion of improved process, the sifting out from the traditions of the craft those parts which are little more than traditional superstition, the strengthening of those traditions of the craft which are almost unconscious science. It is perhaps in its utilisation of external science that the telecommunications industry has been exceptional and exceptionally fortunate in its still short history. The technical aim of the industry may be embodied in a single sentence as being that of obtaining at the receiving end desired signals of the required shape and of such strength as to dominate undesired signals of artificial or natural origin. In pursuit of this aim, the industry has turned to the metallurgist with demands for metals which combine especially high or especially low electrical conductivities, and especially low or high values of temperature co-efficient of conductivity, with other desirable properties, all the combinations being conditioned by the need for preserving the mechanical properties which determine workability and sustained serviceability. It has demanded from him metals with exceptional magnetic qualities and its demands, although they will never be satisfied, have been met with a range of very remarkable materials which are in the main the direct products of that oriented and canalised empiricism which I have already stressed. The industry has turned to the inorganic chemist with demands for materials with exceptional dielectric constants, again in association with stringent demands on temperature co-efficients and mechanical properties. It has asked him for basic materials and coatings giving exceptionally high and exceptionally low electron emissions. It has laid under contribution the whole of his knowledge of phosphors, a knowledge which finds its application in a whole science of controlled infinitesimal impurities. It has asked him for glasses which wet the metals used in his vacuum tube construction and the resulting metal-to-glass seals have completely transformed the design of the thermionic tube and are in the process of transforming a large range of the more ordinary radio components for use under difficult climatic conditions.

The industry has turned to the organic chemist for a wide and ever-increasing range of dielectric materials for high frequency cables, in which he

seeks to combine the good electrical properties of a gas with the good mechanical properties of solids, and the solutions offered include the very direct one of compressing a gas till it becomes a permanent solid. It was by no means to be expected, nor is it generally true, that the new solid would retain or improve on the electrical qualities of the gas, but it was so in one particular case. Industry has turned to the crystallographer, alike in his older and his more modern dress, in such fields as that of the magnetic materials that I have already mentioned and that of the piezo-electric crystals which he has adopted for his own use in the precise control of frequency of oscillation, and has handed to the astronomer for watching, amongst other things, those apparently intermittent vagaries of the earth, as a time-keeper, to which the Astronomer Royal has so recently referred within these walls. The industry has turned to the electron physicist for that intimate knowledge of the behaviour of electrons in the electric and magnetic fields experienced in his thermionic tubes and, amongst others, in the cathode ray tubes which he used partly as an instrument of diagnosis and control, partly as an instrument of display. And here, as in all its other traffic with the external science, it has taken the external scientist to its heart and made him an internal scientist. The industry has turned to those expert in classical optics for a great body of knowledge which can be directly embodied in antenna design and in the unravelling of the problems of the travel of radio waves through the troposphere and the ionosphere.

It has turned to those expert in acoustics, not merely for the solution of its purely sound-reproducing problems, but as a continuation of that transformation of acoustics into optics which was the gift of Lord Rayleigh and the consequent transformation of optics into the optics of telecommunications, which I have just mentioned. It is characteristic of the present phase in telecommunications development that whereas in the 1920's we were inclined to say 'it is all in Clerk Maxwell,' what we now have to say is 'if it isn't in Clerk Maxwell, it's in Rayleigh.' And not the least fascinating of the industry's calls to external science is the story of how the industry called on the geophysicist and the solar physicist for the unravelling of that problem of the propagation of radio waves in the ionosphere which began with the lapse of the scientist into half-scientist when Marconi proposed to signal across the Atlantic.

Dr. W. T. Astbury, F.R.S.

Fibres

THE textile industries are among the oldest in the world, and they were highly developed long before what we now think of as science became established. Over many centuries there has been built up a great body of craftsmanship and experience with raw materials of almost exclusively biological origin—fibres and fibrous structures from plants and animals—and this combination of traditional skill with materials of surpassing molecular complexity might reasonably invite the question what science has to say in such a case. Quite understandably, science had little to say till recently, but at last, over the past twenty years or so, she has intervened and spoken with a voice of genuine authority. The story at the beginning was one of an interplay between industrial needs and the quest for knowledge for its own sake, but now it may fairly be claimed that at least with regard to all future developments, the inspirational lead comes from science.

There must long have been a hankering after spinning filaments in some such way as the spider spins them, but it was not until the latter half of the last century, when methods were discovered of dissolving and reprecipitating cellulose and its derivatives, that anything like an industrial process became possible. Even then, it would not be true to say that the inspiration was chiefly industrial, because the key discoveries were made in the laboratory and arose at bottom probably more from the urge to elucidate the nature of biological structures than anything else. Much as the study of fibres is of industrial importance, it is of still greater biological significance, and it cannot be over-emphasised that the traditional textile materials are biological products, that textiles and biology are therefore inseparably bound up with each other, and that from this viewpoint modern textile science is as fundamental as could well be imagined. The fibre and fabric business is not merely nearly as old as mankind, it is as old as life of any kind, for the most important solid components of all living things are fibrous structures—either visibly fibrous or in the molecular sense—that perform many functions and display an immense variety of properties. Clearly there is inherent in such structures something very special and at the same time supremely comprehensive, something capable of manifold adaptation. That is the lesson that Nature teaches far and wide, and briefly the great gift of science to the textile industries lies in the correct interpretation of that lesson. In detail the problem is difficult—indeed, one of the most difficult in science, if only because textile molecules are among the most complicated we know—but in principle it turns out to be almost childishly simple: the molecules from which fibres are constructed are found to be long chain-molecules, and they lie along the length of the fibre as fibres themselves lie along the length of a yarn. In other words, a fibre is a molecular yarn.

Textile science is thus fundamentally the science of chain-molecules, that is, of linear high polymers; and in its more recent manifestations it becomes one with the science of plastics. When first the rayon industry was founded on the discovery how to dissolve the framework substance of plants, cellulose, and re-precipitate it in the form of fine filaments, this was hardly suspected, and in fact the industry in its early stages was built up rather empirically. All the time, however, chemical and physico-chemical investigations were going on in the laboratory, especially at the universities—investigations not only into cellulose and other polysaccharides but also into the proteins, the most important biological molecules of all, of which silk and wool (among other things) are composed—till finally, in the 1920's, the methods of X-ray diffraction analysis were also brought to bear on the problem. It would be claiming too much to say that X-ray analysis (a pretty 'pure' and academic branch of physics in those days, be it noted) alone gave the solution, but it is true enough to say that it gave the decisive clue that at once

co-ordinated the accumulated jigsaw of facts and settled once and for all that fibres are of the nature of molecular yarns formed from long chain-molecules. From that time on the way was clear—or rather two parallel ways, one continuing the study and exploitation of the natural chain-molecules as found in the traditional vegetable and animal fibres, and the other leading to the synthesis and use of chain-molecules other than those found in nature. Actually, the plastics industry dates also from about the beginning of the century, but strictly speaking its scientific development is quite the same thing as the study of fibres, except that its activities include films, sheets, and other shapes besides. Modern synthetic fibres, such as vinyon and nylon, are simply drawn-out plastics—molecular yarns spun from man-made chain-molecules ; and the whole subject in its essential principles is as striking a case of scientific unification and leadership as could possibly be quoted. Under this leadership biologists, textile people, and plastics manufacturers, whether they recognise it yet or not, are all partners in one and the same great adventure.

Since the last war the scientific investigation of the natural fibres—cotton, flax, silk, wool, and so on—has been prosecuted systematically, more fundamentally in the universities, and more with regard to the immediate needs of industry in the research associations, technical colleges, and industrial laboratories ; and under the guidance of science (still not always received whole-heartedly, as is perhaps only to be expected after so many years of undoubtedly successful craftsmanship) there has dawned a new age in textiles, an age in which, what is more, the unscientific must surely sooner or late go to the wall. I think it may be said without bias that again the more basic advances are to be credited to X-ray diffraction studies, particularly in the protein field, where X-ray researches into the structure of wool and other animal fibres have given a powerful new impetus not only to textile science but to molecular biology and medicine besides. It will be very much to the point here to add a few details about these protein discoveries, because they have indeed now set growing a brand-new branch of the textile industries, and the story is as impressive an example of industry drawing its very being from science as any that has happened. We expect that sort of thing with the electrical industries for instance, that were born and bred in the laboratory and have never been anything really but academic physics on a large scale, but to initiate revolutionary changes in an age-old industry like textiles, that moreover uses raw materials that are the last word in molecular complexity, is something of another complexion that must give the most hardened reactionary to think.

The X-ray study of wool and other mammalian hairs showed that they are of the nature of molecular yarns in that they are constructed from polypeptide chains running in the direction of the fibre axis, as the cellulose chains do in the vegetable fibres, but whereas the cellulose molecules are fully extended, unstretchable chains (which accounts at once for the well-known elastic shortcomings of the vegetable fibres), it was found that the polypeptide chains in wool are ' crimped ' so as to form long molecular springs, which pull out straight when the fibre is stretched but fly back into their normal folded configuration when it is released again. This is the molecular interpretation of the long-range elasticity of wool—quite its most important industrial asset—and the further working-out of the same discovery reveals also the principles underlying the ' setting ' of wool and hair (and incidentally, the mechanism of the ' permanent wave ') and many other features that can only be hinted at here : it leads also to an explanation of the elastic properties of muscle tissue, throws light on the clotting of blood—but this is not primarily a biological review, and the object in mentioning these things is to drive home again the fallacy of thinking of science as anything less than single and indivisible. In the particular case of the protein fibres we have a splendid example both of a debt owed by industry to science and of fundamental scientific advances springing from what started out as an investigation into a frankly industrial problem.

The branch of textiles in which the debt to science is more obvious is, of course, that devoted to man-made fibres. It falls into two sub-branches, one concerned with ' regenerated ' fibres and the other with fibres that are truly synthetic. As indicated above, the basic principles are the same in both, but the former uses naturally-occurring molecules (polysaccharides and proteins) that man has not yet succeeded in synthesising, while the latter starts ' from scratch,' so to speak, and makes first the molecules themselves. Cellulose rayons are become extremely familiar : they are regenerated from wood, cotton, and such-like, and sometimes they are left simply as cellulose and sometimes they are afterwards converted into derivatives—esters and ethers. This industry has now passed well beyond the early somewhat empirical stage, and though it would be flattering ourselves to maintain that there is no room for closer scientific reasoning and control and for a still more searching way of looking at things, there is no doubt that it has taken on the stature of one of the great scientific industries of our time. The business of regenerating fibres from protein material is of comparatively recent growth, and we shall probably have to wait till after the war to see properly how it will turn out on a competitive industrial scale. It is full of promise, however, and I should like to draw special attention to it because if ever there was a case of the textile industries receiving inspiration from pure science, this is it. The reasoned, scientific development of regenerated protein fibres is a direct consequence of X-ray studies carried out in the university.

The argument is as follows. There are many other proteins besides those that are visibly fibrous: such are egg albumin, hæmoglobin, casein, insulin, pepsin, edestin, and so on, and far from being fibres, they may often be prepared as crystals. Their molecules are not of the form of the open chains found in silk, wool, collagen, etc., but are rounded bodies : chemists believed strongly, though, that they must somehow consist of polypeptide chains, and it was an urgent problem how this could be. Now these crystalline ' corpuscular ' proteins perform specific vital functions—hæmoglobin, for instance, carries the oxygen round in the blood—but they very easily lose this property, or become ' denatured,' unless the physico-

chemical conditions are exactly right, even though their chemical composition is practically unaltered by the change. The answer given by X-ray analysis is this, that the polypeptide chains are there in the corpuscular proteins, but they are disguised by the fact that they are folded up and grouped together in the special configurations required for their specific tasks : they lose their special character on denaturation simply by unfolding and becoming disorganised. The X-ray patterns given by denatured proteins are all of the same type, a type, in fact, that may be obtained from stretched wool. The inference is that to convert corpuscular proteins into fibres we have to denature them by some reagent that also dissolves them : the solution will then contain liberated popypeptide chains that it ought to be possible to draw out into molecular yarns in the way that cellulose rayons are spun. Experimental fibres were first made in the laboratory from so-called seed globulins, such as edestin (from hemp seed) and excelsin (from Brazil nuts), but thereafter the development to commercial satisfaction was carried out by industrialist chemists and technologists, using the protein from pea-nuts. The fibres made from pea-nut protein have been named ' ardil,' while ' lanital' is a similar product from the milk protein, casein. (Lanital first appeared as an empirical product about the same time as the general principles were being worked out scientifically and independently.) In America, soya bean protein is also used : a lot of research is now being carried on there on regenerated protein fibres, and recently an account has been given of strong fibres made in the laboratory from egg-white. Regenerated protein fibres have a wool-like softness and warmth, can be dyed with wool dyes, and are also elastic. Their elasticity arises from the circumstance that the unfolding of the original corpuscular molecules is incomplete : sufficient folds remain to imitate the part played by the regular folds found in the natural wool molecule that confer on it the properties of a spring.

After what has been said above about our present-day grasp of what constitutes a fibre and the scientific steps by which that understanding has been reached, there is no need to labour the point that the genuinely synthetic fibres are scientific from start to finish. True, the chain-molecules that have been synthesised so far are much less complex and versatile than those exploited in nature, but they are an excellent beginning—witness, for example, nylon, that has been of immense use in the war effort—and of course they have special properties of their own. It is not simply a question of substitute products : synthetic fibres are supplementary to what Nature has provided, and so, in normal times at least, serve only to increase textile potentialities. At the present rate of progress, and in a sane economic world, there is no knowing to what heights science may lead the textile industries.

It is worth pointing out again, too, that synthetic fibres are thermoplastics. The principles governing their production and properties are an essential part of the scientific laws of the great plastic industries, which strictly speaking include, among so many other things, the manufacture of synthetic rubbers. The synthetic fibres themselves become rubbery at appropriately high temperatures.

Prof. J. D. Bernal, F.R.S.

Summary

ONE thing has been very striking in this morning's contributions. Each speaker talking to the subject of the contribution of science to industry referred almost as much to the contribution of industry to science. It seems to me that we have been looking at the situation too sharply. There are not two different concerns—science and industry—trading with each other and trying to cast up their accounts in order to find out at the end who is in debt to whom. We should rather be dealing with two aspects of a process which has been going on in the world for some three hundred years and which at the moment is developing at a rate which is upsetting the whole course of human society.

In the great movement we call the industrial revolution or the renaissance, the new development of trade and industry occurred at the same time and among the same people who made the new discoveries and the new inventions. In other words, science and industry were born together and have remained the closest of relations.

In the early days, when science and industry were comparatively small affairs, the relationship between them could remain on a personal basis. Even one hundred and fifty years ago, the scientists and the manufacturers were often the same persons or were close friends. Those were the heroic days when Boulton, the great Birmingham manufacturer, his partner Watt, who started as a scientific instrument maker, Dr. Erasmus Darwin, a doctor and botanist, Priestley, the revolutionary Minister and creator of modern chemistry, used to meet together every full moon in their convivial Lunarian Society, and discuss indifferently politics, religion, industry and science. There was no need or place for elaborate organisation ; everything could be settled round the dinner table or in the kitchen-laboratory.

With the enormous growth of both science and industry in the intervening years, the co-operation between science and industry has become necessarily institutionalised and much more complicated, and the two interpenetrate to different degrees in different fields. Our problem is not to separate science and industry and to try and set them up as abstract entities, but to determine the appropriate structure of the common organisation of production in which science and industry play their different but related parts.

The examples that have been given in this morning's Conference have covered a fair range of the different forms of co-operation that are actually occurring between science and industry. We may take the textile industry, of which Dr. Astbury was telling us, as a type of the relation of science to an older, traditional industry. Here occurs what might be called the infiltration of science into industry from the outside. The first element of science to infiltrate was mechanics, at the very dawn of the industrial revolution : the use of inventiveness and mechanical ingenuity to imitate and multiply the speed of the old, traditional processes. Next, in the nineteenth century,

chemistry came in with the substitution of synthetic dyes for natural extracts. Finally, in the present century, molecular physics which reveals the inner structure of the fibres, has entered the field and is leading to a new stage in which the fibre itself, as well as the processes to which it is subjected, will become a scientific product. The infiltration has been a very slow one but constantly speeding up and always tending to reach a critical stage in which, as in textiles, both the processes and the materials are rationally understood.

When we come to the more modern industry, there is no question of infiltration of science into industry : it is rather the reverse, the application of engineering methods to realise the results of laboratory discoveries. In aeroplane design or telecommunication, it was the scientific principles that came first ; the processes and materials are understood from the start and there are no such crises as in the older industries. As Sir Robert Watson Watt pointed out, the communications industry might have been completely disrupted by the many inventions he enumerated, but it survived them because men knew what they were doing all the time. In the older industries all they knew was that what they had been doing was right : they did not understand it but it worked. For that reason change of any sort is resented and resisted and only comes about when it cannot be avoided owing to change in the demand for goods, or the supply of raw materials. Men have been slow to realise the importance of understanding what they are doing and having a theory behind their industrial activity. The idea of a perpetually changing industry digging out its foundations all the time, is new, and not one that the older industries will readily accept, but until it is accepted they will be subject to recurrent crises. Both the basic industries of this country, cotton and coal, are now suffering from the fact that the industrial revolution started in this country. They are now having to carry the dead weight of this original investment ; not so much the dead weight of out-of-date mines and mills, but that of the persistence of the attitude of mind, of rule of thumb and hard business sense which, though it created the industrial revolution, is now the biggest brake on it.

If we ask what is the proper preparation or organisation of the scientific side of industry, we can answer with the elementary and distressing fact that we do not know. Not only do we not know, but no one is attempting to find out. There is, as far as I know, no one in this country whose job it is to find out how science can best be used in industry. The subject is consequently in a pre-scientific stage. Many people have ideas : a few have considerable experience. All kinds of organisation of scientific research in industry are being tried out, some good, some bad : but we do not know which are good and which are bad—or why. As in industry itself, we have to understand what we are doing before we can start putting it right. An illuminating example of the beginning of a real study of how science is applied in industry is contained in Sir Robert Watson Watt's address this morning. One could see there the first step of the analysis—tantalising because many of the examples had to be left out—of the relations of science, engineering and business practice. The case he chose was the simplest from the point of view we are discussing, because he dealt with an industry which is less removed from science than any other. Even here the problem is a very complicated one. There are internal scientific developments and calls on external science as well. Questions of empirical, experimental and theoretical research have already arisen and in many cases solutions are still being arrived at by intuition without any scientific study of the process of reaching them.

In another way, Sir Robert pointed to one of the limitations of scientists in industry : his liability for making ex-cathedra statements which block further inquiry until some practical man with the ' fool ' experiment opens it up again. But Sir Robert demands of scientists a degree of superhuman carefulness which I do not think will ever be reached. The scientist works within a certain framework of theories and assumptions. If he says, incautiously, that something is impossible, it is because most of the proposals of non-scientific people are impossible. I remember in the early days of the war, some magnificent examples of this, such as the idea of suspending a rubber mat over London so that the bombs would bounce off it. But it is only when a proposal is very definite that it can safely be shown to be impossible and, even then, it may be simply a bad instance of a principle which might be useful. Most new ideas are much vaguer, such as finding a new ray to cause aeroplanes to disintegrate in the air. Most scientists would say that that is impossible ; but there they are on most dangerous ground. The scientist, as we know from experience, ought to have the feeling that he is more likely to be wrong than right, not because he argues wrongly, but because he does not know what he is arguing about. If he reflects on that he will probably not condemn any proposal as impossible ; that does not mean that he can afford the time and effort to attempt to realise everything that he cannot be reasonably sure is impossible. Especially in industrial science it pays to explore the known ways of achieving one's end before embarking on the unknown. The first stage is to discover what it is that you really want to do. The scientist is often asked questions which, whether they are answerable or not, are very often the wrong ones. It is a valuable practice to try to find out, not what a man is asking you, but what he is really trying to get at—what is behind his question, not the question itself. Then you get somewhere.

You can never remove the possibility of a scientist being wrong, but you can always reduce it, and the failure of the scientist is of observation not of logic ; and it is equalled by the failure of the industrial side to understand the scientist and to profit by him. That was the whole history of the last century. I am not sure that wireless was not discovered in 1795. At any rate, as Sir Robert has told us, it was re-discovered in the middle of the last century and not used until the present one. That might be excused as an idea too novel to be readily accepted but it is clearly true in much more practical fields. Mercer discovered mercerisation somewhere about 1840 and it was not really used until 1890. There was an

industrial process capable of immediate application but not taken up. The failure to use discovery is still going on. We may not have to wait half a century, but in these days the loss of a year or a few months means as much as a decade in the nineteenth century.

The failure to understand and work with the scientist is another example of the lack of co-ordination. It would be easy to multiply examples of the lack of co-ordination between scientific discovery and its application. The practical answer is that we shall never get rid of this difficulty until we set about getting to the bottom of it. We ought to have a body, quite small but of the highest intellectual ability, inquiring into this question of the organisation of industry and science with the object of getting the best working partnership. It should not be asking how much industry owes to science, or science to industry, but finding how the partnership works, examining the best existing methods and discovering the most hopeful ways of improving them. That is an immediate thing which the British Association might well put in hand.

While waiting for the answers we know one thing which has already been brought out clearly in this Conference. We are lamentably short of scientific and engineering workers in this country and unless we take straightforward action to get more, we shall fall, not to second or third place, but out of the running altogether as an industrial nation. Mr. Bevin gave figures on the tragically small numbers of draughtsmen and radio technicians, but he could have taken any section of scientific workers at any level and drawn the same conclusion. I believe that, apart from genius, of which we have our share, we have an absolute shortage of scientific manpower of all grades. The extent of the shortage is more difficult to assess. Any attempt to work out the best proportion of scientific to industrial effort, based on the returns that science has already brought to industry, shows that it is far beyond what we can practically achieve. It is, however, worth going all out to increase the proportion without any fear of overtaking it. If we had ten times the proportion we would still be no better off than the Soviet Union to-day. The needed increase is limited by the rate at which people can be trained. We should organise so as to get that rate as high as possible in schools, technical institutions, universities and research laboratories, so that in the immediate post-war period we shall be turning out as many trained scientists and technical workers as we can, for we will need them.

FUNDAMENTAL RESEARCH IN RELATION TO INDUSTRY

FRIDAY, JANUARY 12 : AFTERNOON SESSION

ADDRESS BY THE RT. HON. LORD MCGOWAN, K.B.E., CHAIRMAN OF THE SESSION

INDUSTRIAL manufacture is, and always has been, an art. Until the industrial revolution the art of manufacture was handed on from father to son or from master to apprentice. It was only when the factory system appeared that it was possible to apply science to industry. And it was only about that time that science began to develop on lines which could be of use to industry. I am not going to discuss which was cause and which was effect ; both were perhaps due to a political development which made both the industrial revolution and the growth and application of science possible. But we can easily see how these two movements helped each other. About a hundred years ago the Prince Consort did much to encourage the marriage of these two movements by his interest in the Royal Society of Arts and in the 1851 Exhibition of Science and Art held in Hyde Park. Also I would remind you of the work done by the Royal Institution which started a hundred and fifty years ago, ' to teach the application of science to the common purposes of life.'

Manufacture is still an art, but we no longer depend solely upon what we have learned from our fathers and masters, for science has taught us how to develop new arts of manufacture. It has brought us the telephone, electricity, wireless, television, the motor car, new textiles, really effective medicines, the aeroplane, machine tools and many other inventions which all add to the amenities of living.

In what I am going to say this afternoon, I shall have principally in mind the industry in which I have spent my life—the chemical industry—and I shall draw my examples from it ; but I do not think that this will make my remarks any less general, as I believe that the same principles apply to the application of science and research to any other industry. New chemical industries arise from scientific research and scientific research is used in developing new arts for use in all industries, new and old.

First of all, what do we mean when we speak of ' fundamental ' research ?

The word ' fundamental ' does not itself define our meaning clearly. A distinction may be made between research which is done with the sole object of making a contribution to the sum of human knowledge, calling this fundamental, and research which has been undertaken with a definite industrial objective, calling this applied research. But this leads us into a difficulty, for the absence

of an industrial or financial incentive to the work does not alone make it fundamental. Some of the recognised classics of fundamental research, such as the work of Faraday and Clerk Maxwell, have led to immensely profitable industrial results. But surely this work would have been just as fundamental if Faraday and Clerk Maxwell had been able to foresee its results.

Without attempting a definition which will cover every conceivable case, I think we can express the idea with sufficient accuracy by considering as fundamental any research which is primarily directed to increasing our understanding of the causes of phenomena and of the principles and generalisations which make up the so-called 'laws of nature.' Such research may or may not have a bearing on a particular practical problem.

For many centuries after the fall of Roman civilisation, Europeans were content with the fuller development and exploitation of their home territory. With the discovery of America it became apparent that rich rewards awaited those who were prepared to venture their lives and substance in expeditions to unknown regions. Not all such expeditions were successful, but this adventurous spirit resulted in making the huge and unsuspected resources of the New World available to civilised mankind. There is still scope for such ventures, which we might well call 'fundamental geographical research,' but the same outlook can now be applied to extending the frontiers of scientific knowledge. If we devote time and money to the experimental study of natural phenomena in fields where our present knowledge is slight, it is not unreasonable to expect that discoveries will be made which will, in the long run, have far-reaching effects on our everyday life.

Applied research may use empirical or fundamental methods. Suppose we have to manufacture a new chemical, we first make some experiments in the laboratory to find a method which gives us a good yield ; then we construct a plant, using the arts of the chemical manufacturer to make the product. I should call this the empirical method. The fundamental method would be to determine all the chemical equilibria and velocities of reaction and their dependence on temperature and pressure, and to determine the amount of heat given out or absorbed at each stage of the process. Armed with this knowledge, we can design a plant of just the right size to make the desired amount of the product each day. The heating arrangements and the coolers, the filters, the stills and the pipes will all be exactly of the right size, so that no money is wasted in building parts of the plant too large. The plant will also run exactly as we expected it to do and there will be no loss of time in getting into full production. This is the fundamental method of building a plant. It consists in finding out how and why things happen before making the designs.

This fundamental method is the one we like to apply and we do apply it when we can. It is usually applied in cases where large tonnages of a product have to be made or where the manufacture of a high priced product is difficult.

I would remind you that during the last two centuries there has been built up a considerable art of chemical manufacture. According to the chemicals which we are using, we know how to construct reaction vessels, stirrers, autoclaves, towers and stills. This art of manufacture grew up empirically, but as our knowledge of the fundamental sciences has opened up, we have been able to improve the design of most types of plant, but we never have all the fundamental scientific knowledge which could be useful to us when we are designing a chemical plant. The result is that we have to make the plant larger than we should do if we had more knowledge. We increase the size of the plant by a 'safety factor.' It may be 20 per cent., it may be 50 per cent. It would be better to call this an 'ignorance factor' instead of a 'safety factor.' This ignorance factor is a grave loss to all industries, both in the construction of plants and in the running of them. It has an importance in its effect upon the balance sheet—a point of view which I have always before me. It not only affects my own balance sheet, it is a serious factor in the national balance sheet.

The only method of diminishing the magnitude of the ignorance factor in building and in running plants is by learning more about the laws of nature and by using the knowledge.

It is of interest to mention here that in the United States, where there is strong competition but where there is a ready market for a new product, it is quite usual to start building a plant before even empirical experiments have been made in the laboratory, to build the plant large enough to be quite sure that it will give the required output, and as soon as it is built to alter it as may be found necessary. This method is extravagant but it is the method which has enabled the Americans to build large plants and bring them into operation in record time.

It is useful to classify research in the chemical industry in order to consider it in more detail and to see how fundamental

research is related to it. I shall consider: (1) process research, (2) chemical engineering research, (3) research into industries which we serve, (4) speculative research.

(1) *Process research* is carried out to maintain and improve the quality of our products and to ensure the economical working of our factories. In practice we find that usually a mixture of empirical and fundamental methods is used. Process research always shows us clearly what large gaps there are in our knowledge and makes us wish to find out more about the fundamental causes of phenomena. But there are so many problems to be solved that we can only do fundamental research on those which are of considerable importance for the industry. It is not only a matter of expense, but also of man-power and laboratory accommodation.

(2) *Chemical engineering research* is largely a branch of physics and mathematics, as well as of engineering. Progress can only be made by the fundamental approach, and results can only be obtained after long and arduous work. But the knowledge obtained is of great importance to the industry and well worth the trouble and expense of years of research.

(3) In order to sell our products we have to learn as much as we can about the industries in which they are used. In many of these industries the art of manufacture has been developed empirically and science is only gradually creeping in to improve the art. But, however good and successful the art of manufacture may be, it is always better to know the fundamental scientific facts about an industry. In order to sell our goods we try to provide fundamental knowledge to the industries which we serve. The agricultural industry is an example. We have done a good deal of fundamental work in agriculture which has had its effect upon the industry.

(4) *Speculative research* is so varied that I can only mention examples of the methods used in one or two branches of the industry. The method varies with the industry, with the subject, and even more with the man carrying it out.

We have heard of forty men working in one laboratory, all with an identical piece of apparatus and each of them determining the effect of light of the same wave length on two or three chemical compounds a day, and the work continuing for one or two years. The Germans tested many thousands of chemical compounds over a period of twenty or thirty years to find two or three which were effective in fighting malaria. Of course when they found one which was at all active, they made all the compounds they could think of which contained the same chemical groupings, in the hope of finding one which would be very active. This method succeeded and some useful drugs have been obtained in this way. But now that we have obtained active drugs for some purposes, pathologists, chemists and physiologists have discovered something of the fundamental action of these drugs, and it seems that progress will be more rapid in future.

Some years ago, we started an investigation into the effect of very high pressures upon chemical reactions. We were using pressures up to about 3,000 atmospheres. The general result of the work showed that at moderate temperatures ethylene was among the more reactive compounds, and in one case a white solid was deposited in a portion of the apparatus. The investigation of this material led to the discovery of polythene, which is now manufactured on a large scale and has been of considerable importance during the war.

The method here was to carry out fundamental research in the little known field of high pressures and high temperatures and at the same time to keep an eye open for any opportunity of developing some aspect of the research into an industrial operation. Everything turned out as it should do, but when we look back upon what happened ten years ago we realise that as soon as the original fundamental research yielded polythene, all the men available were turned on to the problem of ethylene polymerisation and good fundamental work was carried out on the kinetics of polymerisation, the nature of the catalyst being discovered fairly rapidly. But the original research was dropped in the excitement and enthusiasm of developing the new product.

There is no doubt that it is difficult to carry out fundamental research continuously and methodically in a laboratory where interesting and exciting industrial developments are taking place.

It may be useful to discuss where fundamental research should best be carried out. Besides industrial laboratories, there are academic and Government laboratories to be considered. Fundamental research originated from the academic laboratories, but it is, of course, impossible to leave all fundamental research to the universities. Government laboratories, especially the National Physical Laboratory, and to some extent Service laboratories, have done important fundamental research, and we look forward to receiving even more help from them in the future.

My Company had decided, before the war, to have a laboratory for fundamental and

speculative research only. It will be geographically and administratively separated from laboratories attached to factories, so that the workers will not run the risk of being taken from their fundamental work to solve urgent problems connected with production or sales. We have had an agricultural laboratory run on these lines with very successful results.

Although we intend to have a special laboratory for fundamental research, we intend still to encourage it in the laboratories attached to our factories, since we believe that a certain amount of this type of work must be carried out in every laboratory if it is to remain alive. But this does not mean that there is any danger of reckless or unhealthy competition in fundamental research between academic and industrial laboratories. If all the industrial laboratories in the country decided to carry out substantial programmes of fundamental research they would, even then, be able to tackle only one tiny corner of the whole field of fundamental research.

Always the great bulk of the work will be done in university laboratories, and it is right that it should be done there, because it is only if there is a large and very active spirit of research alive in the universities that industry can hope to get, not only the ideas which can be developed into new industries, but also, which is even more important, the trained scientists to carry out this development.

Prof. P. M. S. Blackett, F.R.S.

1. *Relation between Fundamental and Applied Science.*—As the opening speaker in this session on Fundamental Research in relation to Industry, I intend to speak about some of the more general aspects of this relationship, though with chief emphasis on the physical subjects. I think it is of considerable importance that this relationship should be discussed, as it is one of some complexity.

There will, I think, be general agreement at this conference about what is generally meant by *fundamental science* : it is the investigation into the nature of the material world with relatively little regard to immediately useful results ; just as *applied science* is the similar investigation with relatively great regard to immediately useful results.

What is the correct balance between these two aspects of science, considered from the standpoint of material prosperity ?

Clearly fundamental science can be taken as a relatively long-term social investment, which can be expected to pay high but chancy dividends at some quite uncertain period in the future, whereas applied science can be considered as a short-period social investment directed towards more immediate dividends. Confirmation of the correctness of this view is obtained by considering what has occurred during this war.

It is noteworthy that in the years 1939–44, active work in many branches of fundamental science has been almost completely stopped, in the interest of expanding applied science to the utmost. Though it was undoubtedly right that this was done, particularly in the early critical years of 1939–1941, the precise reason why it was right is often overlooked. It was right, not primarily because there was a war on, but rather because it was assumed that the war would be short ; and the war has already lasted long enough to raise the doubt whether, as it has actually turned out, we may not have overdone somewhat the sacrifice of long-term investment in fundamental science for short-term investment in applied science. Or perhaps it might be more true to say that we may have neglected unduly some of the more basic aspects of applied science in comparison with work for immediate application.

If, at the present time, the war were still expected to last for many years, then clearly we should have to re-create our fundamental science, at the expense of our immediate development work, in order not to be defeated in ten or twenty years' time.

In any economy at a given stage of development, there is clearly a desirable balance between investment in fundamental science and in applied science. The desirable balance will clearly depend on the social conditions and may differ in different branches of science. For instance, some things that I will say about physics may want considerable modification when applied to biology.

Fundamental and applied science are both equally good science. In fact most of the actual scientific activities of a fundamental and an applied scientist are essentially alike, though the conditions under which the work is done, and in particular the personal freedom of the scientist, may be distinctly different.

The greater social prestige with which pure science is often credited is derived to some extent just from these greater personal amenities, with which, as in a university, it is often associated.

Pure science as it exists at present in this country has two distinct functions, in relation to the advance of material prosperity. Researches carried out in universities, technical colleges and research institutes provide most of the fundamental advances in our knowledge of the material world, and so of our power to change our environment and our way of life. And the universities and colleges in which fundamental research is carried on provide the main supply of trained scientists to staff the laboratories of applied science in Government establishments and in industry.

The experience of the war years has shown very clearly that first-class fundamental scientists have proved, in very many cases, extremely successful and versatile applied scientists. One of the reasons is that a pure research scientist receives an intensive training in the fundamentals of science and in research methods and is, or should be, continually breaking new ground both in the experimental and theoretical fields. He is thus often able to tackle an applied problem from fundamental principles, and so often from quite a fresh standpoint.

On the other hand, the conditions under which much applied work is done are often senselessly restricted. Much needs to be done, both in

Government laboratories and in industry, to improve these conditions.

The question now arises as to what are the conditions in peace time in which fundamental scientists should undertake applied work. The effect of this being done is to sacrifice the long-term dividends expected from fundamental science for the relatively immediate gains from applied science. This is clearly justifiable in a short-term crisis, as in a short war, or in some short-term crisis in peace-time. The immediate need of rehabilitating the world after the war might well be held to constitute such a short-term crisis, but a closer analysis suggests that this view is incorrect as regards the physical sciences, but may be correct for some biological and medical sciences. For it must be remembered that the rehabilitation of the world after the war is part of the general problem of raising very markedly the living standards of the mass of the population. This is the paramount need of our epoch, and is too big a task to be achieved in a few years. In fact it is a relatively long-term problem, long-term enough at any rate to make it essential to keep a proper balance between pure and applied science. For no adequate rise in world-wide prosperity is possible without great advances in our fundamental knowledge of the material world.

There is some danger that the present very general appreciation of the urgent need to improve the application of science to industry and general human needs, combined with the personal feeling of many of the scientists of wanting to help in a practical way, may lead to an undue transfer of scientists from pure to applied work.

Large industrial firms and Government departments should be chary of enticing by big salaries our best fundamental scientists into applied science, as a supposed remedy for the ills mainly due to former managerial incompetence, or to the workings of an economic system which has been crazily out of joint. And our fundamental scientists should equally be chary of deluding themselves that it is their social duty to accept such jobs. The economic disease, of whose symptoms we were so painfully aware in the 1930's, is too deep-seated to be cured by a rush of pure scientists into applied work.

Let us consider for a moment just what sort of applied *physical* science is in fact needed. Leaving exports out of account for the moment, it is quite clear that the existing quality of the majority of articles of private consumption available to the prosperous classes is reasonably adequate. What is inadequate is the number of people who can afford them. Where quality needs improvement is in the direction of improved durability, not mainly towards novelty and new gadgets.

Modern refrigerators, radiograms, clothes, houses, etc., are good enough already to give their qualitative improvement not a very high social priority. What is needed is many more of these things. Thus the urgent priority is to improve the materials and productive methods by which these consumption goods are made, in order to reduce their real cost in human labour, so enabling them to be distributed to the whole of the population. It must not be forgotten that the houses of a large fraction of the population have not even baths !

It is generally recognised now that many sections of the factory industry of this country are very inefficient compared with American standards ; in fact the output per head appears to be more than twice as high in the U.S.A. This is a serious situation, of which the causes are clearly complex, but include the economic slump conditions of the inter-war period, the archaic structure of much of British industry, a considerable degree of managerial incompetence, some Trade Union conservatism, the dominance of non-technical directors, an inadequate education system, etc.

The immediate remedy lies not so much in the application of more applied science at the level of the industrial research laboratory producing novel selling lines, but much better engineering at the workshop and drawing office level, with the object of cheapening production. More important still, of course, is the general economic problem of ensuring full capacity working, regular demand, cutting of advertising and distribution charges, etc.

Scientists should never forget that all attempts to ensure the maximum utilisation of science for human welfare under the economic conditions of the 1930's will fail. For it is ludicrous to imagine that science will be fully utilised to increase production when the existing productive machine is only partially employed. In fact, the attainment of full employment in peace-time is the essential condition for the full utilisation of science. Any scientist who supports the full utilisation of science for human welfare, but does not support the social and economic measures necessary to ensure the full employment of the existing productive resources of the country, is guilty of intellectual inconsistency ill-befitting his profession. But unfortunately scientists no less than other men are easily led into intellectual inconsistency through lack of the moral courage to think clearly.

In this connection it may be worth while quoting a well-known American columnist.

' The fact that I do not think things through is no proof that I am unable to do so, and those who leap to this conclusion are themselves guilty of slapdash thinking. I can think things through, but I don't like to, because I always arrive at conclusions very disagreeable to me and find myself in the company of persons and beliefs with whom and with which I would not be found dead.'

The conclusion of this argument is that it is socially undesirable that too much of our scientific effort should be devoted to the improvement of consumption goods. It should be devoted to the improvement of materials and of productive processes generally. There is a grave danger, even a certainty, that this misdirection of effort is just what is likely to happen in many industries during the post-war years ; for the short-term interest of manufacturers will often be to cash in on the expected boom in consumption goods, and to neglect the basic applied work needed for a long-term increase in productivity.

Let us take an example from radio. The great technical advances of the last decade, and the great number of able radio engineers and scientists who have been trained, should be devoted, not mainly to the production of better radio and television sets, but to the development of auto-

matic methods of control and measurement, so as to improve the production processes of industry in general. The prospects of this road being energetically followed do not seem very bright.

In the case of weapons of war, including in this category all aircraft both civil and military, the quality of the final product is of paramount importance. It is not likely that these aspects of applied science will in fact be neglected after the experience of this war.

The export position is difficult for a non-expert to discuss. But fundamentally what the world needs is a greatly improved productivity from industry rather than more novelty in the products.

Except under conditions of short-term crisis, it is the argument of this address that the balance between fundamental and applied science must be continually maintained, and consequently that pure scientists must in general stick to their own job of fundamental research.

This by no means implies, however, that pure science should be carried on independently of applied science. On the contrary, a close relationship is generally desirable and often essential.

Firstly, applied science continually produces new techniques, materials and instruments which provide invaluable tools for the fundamental scientists, e.g. measuring instruments, valves, photographic plates, etc. The fundamental experimental scientist must therefore keep continually in touch with technical developments.

Secondly, applied science continually throws up new problems of fundamental scientific interest. In fact, a great part of present-day knowledge of the material world derives directly from the study of practical problems, e.g. thermodynamics from the steam engine, etc.

Thirdly, all new knowledge acquired in the pure research laboratory must, wherever applicable, be quickly utilised by the applied scientist.

Much fundamental science in this country has suffered by lack of this stimulating contact with applied science. One meets sometimes the boast by a pure scientist that his work is quite useless, with the implication that it is thereby somehow 'better." This is just a silly conceit—the rather pathetic snobbery of the academic isolationist. A problem of pure science, which has a practical bearing, is more worth studying than a problem of equal scientific interest, but without an obvious practical bearing. A very considerable amount of pure scientific work actually carried out is neither interesting scientifically nor useful. What the pure scientist must avoid is to be put off the scent of some far-reaching scientific advance by considerations of short-term applications.

A great deal needs to be done in this country to bring fundamental and applied science into closer relations with each other to the mutual advantage of both. Obvious measures include greater interchangeability of personnel, contact through attending scientific conferences, etc.

2. *The Organisation of Fundamental Science.*—The comparative excellence of many branches of fundamental science in the United Kingdom in the last few decades—contrasted with the comparative failure in many branches of applied science—must not blind us to the necessity of taking energetic steps to ensure that fundamental science in this country develops in the future to the highest possible level of fruitfulness and new discovery. To ensure this, it is clearly impossible to leave the development of fundamental science entirely to the local initiative of the various universities and to the whims of private benefactors. Some central guidance on major matters of policy is not only desirable but is essential if the case for increased resources is to be adequately put to the relevant Government authorities.

Up till about 1930 fundamental physical science has not needed much provision for elaborate and expensive equipment. But a critical stage has been now reached in experimental physics, in that large and elaborate equipment is an essential tool to the rapid exploration of fundamental physical problems. Further, the younger generation of experimental physicists, as a result of their experience in relatively well-equipped Government laboratories, have learnt how much more quickly progress can be made by the use of adequate workshop and drawing-office facilities.

It is convenient to draw a distinction between the problems of raising the general level of the physical laboratories of the universities, more or less independently of the type and quality of the research work in progress, and that of providing additional resources for especially fertile or expensive fields.

The former task, that of providing for what may be called ordinary expenditure, which does not need an intimate acquaintance with the detailed progress of scientific research, seems best handled by the University Grants Committee. The latter task, that of allocating the extraordinary expenditure which needs an intimate knowledge of the detailed progress of scientific research and of the abilities and needs of the chief research workers, might be mainly the responsibility of the Royal Society.

The resources necessary for different kinds of physical research vary very greatly. Some laboratories will be able to function efficiently on or near the minimum standard. Others will need large additional resources, for expensive equipment, large teams of research workers, expeditions, etc.

These additional resources must be allocated primarily according to the ability of the research workers, to the productivity of the research teams and to the needs and fertility of the different fields of research. Men who show themselves able to lead and direct others should be provided with the resources necessary to build up efficient research teams. The object must be to endow ability, not to subsidise mediocrity ; academic equalitarianism is of out place : maximum and not minimum standards are essential ; exceptional ability must be given the maximum resources it can usefully employ, not the minimum it can make do with.

This general guidance of the fundamental science of this country should be the concern and responsibility of the scientists themselves. The Royal Society and the other scientific professional institutes and societies must find and work out methods by which this guidance can be efficiently and democratically exercised. If they do not do this, the guidance will be either lacking or exercised bureaucratically from the top.

The Royal Society, if it undertakes this task of advising on the allocation of grants, especially of extraordinary expenditure, will inevitably build up a comprehensive knowledge of the fundamental

scientific research of this country, and by its allocation of grants will exercise some guidance on future developments.

An accusation that such guidance would mean the detailed control of fundamental research according to a programme set by a Government department does not even need refuting. It is just this suggested type of general guidance that has in fact been exercised in certain fields by the Rockefeller Foundation.

Although it is clear that much the most urgent task is to ensure that adequate total resources are available to fundamental science after the war, it is also clear that it would be very valuable to make a broad review of the existing balance of the fundamental science of this country, so that attention can be drawn to over-cultivated as well as to under-cultivated fields. In the field of physics, for example, are we investing our limited resources wisely as between, say, physics of the solid state, bio-physics, nuclear physics, low temperature physics, geo-physics, etc.? Have we too many small and inadequately developed schools in some fields, or none at all in others?

As a result of the natural development of a science under the joint influence of its own internal logic and of external stimulus, the fertility and importance of the different fields of research are continually changing. It will often happen in the future, as it has in the past, that these developments and changes in emphasis accord ill with the inevitably greater rigidity of the teaching organisation of the universities.

Border-line subjects, in particular, continue to develop in importance, and much consideration will often have to be given to decide whether some new border-line subject should be encouraged to develop into a normal part of a university curriculum or whether it should be covered by other means, for instance by the establishment of a research institute divorced from teaching.

In this discussion, fundamental science has been considered solely from the utilitarian aspect of a long-term social investment which is likely to pay large dividends in human welfare at some future date. Deliberately, no reference has been made to the intellectual and cultural value of fundamental science.

It is undeniable that the profession of scientific investigator is very attractive, and that the investigator himself is largely inspired to his best work by the personal satisfaction derived from the practice of his craft, and from exercising his intellectual curiosity. Again it is equally undeniable that great scientists rank among the greatest men of history, and that the structure of organised knowledge achieved by their work is one of the greatest and most permanent achievements of mankind.

A time may come when these two motives, the personal satisfaction of the practising scientist, and the intellectual satisfaction derived from the study of science, may be sufficient justification for society to endow pure science heavily—though there will be other competitors in music and the arts, where very similar satisfactions can be claimed.

But this time has not come yet and the demand for extended resources must be made on more utilitarian grounds. The great problem of mastering poverty and disease are as high in social priority in peace-time, as are the technical military problems during the wars, which this former problem, unsolved, has had so large a part in causing. But this task of raising the health and living standards of mankind is a problem of years and decades, and demands a much greater fundamental knowledge of nature than we have now. Thus, in our generation, the pursuit and encouragement of pure science must be considered primarily as a utilitarian long-term investment for the material good of mankind. Only when we have succeeded in solving the great social and economic problems of our time, which are now so tragically impeding the advancement of mankind, will it perhaps be legitimate to consider pure science primarily from the standpoint of the personal satisfaction of the scientist.

Prof. E. C. Dodds, F.R.S.
Biochemistry

I PROPOSE to approach the problem of chemistry from an angle rather different from that of previous speakers.

It is not necessary to redefine what we mean by fundamental research. It is enough to say that the term really applies to research for its own sake, and not to investigations directed towards a certain end. It follows that all industrial development must originate, if one goes far enough back, in fundamental research. I propose to take three examples of where such research has had a profound influence on the chemical industry, particularly in this country. It is interesting also to indicate that the three examples given represen entirely British discoveries, made either in this country or in the Empire.

The first observations to which I will refer are the classical experiments of the late Sir Frederick Banting and his collaborators. Those of us who can remember the state of medicine before the year 1921 will always regard diabetes as one of the most tragic of diseases that the physician met with. In a severe case little hope could be offered, and the patient literally died of slow starvation. Admittedly, life could be prolonged by skilful dieting, but the life of the individual was miserable in the extreme and if death did not supervene from diabetes, some intercurrent infection usually carried the patient away. Until 1921 there was no fundamental treatment for the condition, despite the fact that a great deal had been learnt about the mechanism of the disease.

In 1889 it was shown that removal of an abdominal gland, the pancreas, in experimental animals, would cause the disease to appear. The administration, however, of every type of extract of the pancreas failed to control, or in fact, to have any action on the course of the disease. Banting and his collaborators attacked the problem in an entirely detached manner and, as a result of extremely ingenious experiments, they showed that if one obstructed the duct of the pancreas, that is to say the tube connecting the gland with the intestines, although the pancreas shrivelled up, the animal did not develop diabetes. After leaving the animal for some weeks, Banting killed it, cut out the degenerated remains of the gland and made an extract of this tissue. This he found

contained the long-sought controlling agent of diabetes, namely, insulin.

The effects of this discovery on industry were immediate and extensive. Obviously the Banting method of manufacture was right as a fundamental experiment, but could not be used as a method of industrial production. Very quickly methods were evolved whereby material from the slaughter house could be used, and from 1921 onwards a vast world industry was created for the manufacture of this drug alone. The ramifications are very extensive, beginning with the offal trade in the collecting of the pancreas. Then there is the question of preserving the pancreas, refrigeration and so forth, before it reaches the chemical manufacturer. The actual production involves the use of large quantities of organic solvents and requires very skilful manufacturing operations. The material is sent out to the world as a sterile solution in rubber-capped ampoules. The importance to industry of such a discovery is obvious, since, apart from the question of the business involved in the manufacture and sale of insulin, its prestige value is very great and it acts, so to speak, as an 'ambassador' for other British products.

The second discovery to which I will refer is one of such recent date that it will only be necessary to mention it briefly, namely the discovery by Sir Alexander Fleming of penicillin, the wonderful curative agent produced by the mould *penicillium notatum*. Sir Alexander Fleming, in 1929, working in the laboratory of St. Mary's Hospital, made the classical observation that an accidentally contaminated Petri dish on which staphylococci were growing showed destruction of the staphylococci in the regions which were infected by the contaminating mould. From this beginning, Fleming saw the possibility that the antiseptic produced by the mould might be of value in human therapeutics. He proposed the temporary name of penicillin for the substance. A great deal of work was undertaken to produce the substance and many difficulties had to be overcome, and with this work the name of Sir Howard Florey is associated.

To-day we are all familiar with the miraculous cures which are constantly being published as wrought by penicillin. Conditions which were hopeless before now clear up in a relatively insignificant time. Whilst penicillin will not cure every type of infection, there is no doubt that it is the greatest therapeutic agent yet discovered. Its effect on industry, and indeed on the whole of human activity, cannot as yet be assessed. In the first instance it is perhaps not going too far to state that penicillin will cause a complete revolution in the whole of the drug-producing industry. It is always unwise to be too sweeping in one's prophecies, but there appears to be little doubt that, when production is sufficiently good, penicillin or some similar substance will displace practically all other antiseptics applied to the human body, because penicillin is the only antiseptic which combines astonishing activity with a virtual absence of toxicity. The phenolic types of antiseptic damage leucocytes and therefore must be considered inferior to penicillin. What effect will penicillin have on the death-rate in, let us say, countries like India? It is perhaps not going too far to suggest that penicillin, when it is possible to administer it in unlimited quantities, will have a profound effect on the population of regions like the Middle and Far East, where the death-rate, particularly from puerperal sepsis and infections of infants, is so high. If the death-rate is lowered then the increase of population will bring with it a whole train of problems of providing for the millions whose lives will be saved. Again, the use of penicillin in the treatment of venereal disease will certainly bring about very considerable alterations in the pharmaceutical industry which supplies drugs for the treatment of these prevalent conditions. Yet again, the effect of penicillin on medical education cannot be foreseen at the present time, but it is quite possible that a great many of the conditions about which students have to learn to-day will be relegated to footnotes in future text-books. It is perhaps one of the few discoveries which, we hope, will tend to make medicine easier and not more difficult.

Finally, I would like to refer to the synthetic œstrogens, which are having a profound influence at the present time on many aspects of biological research. These substances, of which stilbœstrol, hexœstrol and dienœstrol are the most common, were first produced by Sir Robert Robinson and myself and our colleagues. It will be remembered that some fifteen years ago the female sex hormone, œstrone, was isolated and its constitution determined. It is a very complex substance, being related to that group of compounds known as the sterols and possessing a structure which defies anything but an academic synthesis. My colleagues and I were able to show, some ten or more years ago, that this elaborate constitution was not necessary for the biological activity and that relatively simple compounds would produce all the qualitative effects of the naturally occurring substance. Our first compound, however, only possessed a minute fraction of the activity of the naturally occurring substance, in one case not more than one-millionth of the activity. By a long series of investigations we eventually arrived, in collaboration with Sir Robert Robinson, at the substances already mentioned.

The interesting theoretical point is that these compounds bear no chemical relationship whatsoever to the naturally occurring substance, and we had therefore established the principle that it is possible to imitate all the complex activities occurring in nature in a substance that bears little or no resemblance to the instrument used by nature for the purpose. Another curious point is that these compounds are actually more active, weight for weight, than the natural substance. They are very simple to make and can be produced in huge quantities at very low cost. Unlike the naturally occurring substance, they are highly active when taken by mouth and do not suffer from the disadvantage that they have to be injected subcutaneously. This means that their field of application is very much widened, since they can be given to outpatients over long periods. They have become standard agents in the biological research laboratory and have found an extensive clinical application, the most common being their highly successful application to the treatment of those distressing symptoms characterising the change of life in women. Extensive publications show that by the use of these sub-

stances the symptoms of this trying period can be virtually abolished.

One of the most astonishing uses of these substances is their employment in the treatment of one form of cancer, namely that of the prostrate gland. It has been shown that the daily administration by mouth of one or other of these substances will in most cases effect a complete symptomatic relief of this terrible disease, and large numbers of patients have been maintained in good health and symptom-free condition for long periods. This is the first time that any form of cancer has been affected by a medicine administered by mouth. Whilst, of course, the utmost caution in interpreting these results must be exercised, and in no circumstances must it be supposed that this treatment will be of value in types of cancer other than that of the prostate, there is now no doubt that it provides us with a new approach to this disease.

It is very easy to picture that the synthetic œstrogens have had a profound effect on the pharmaceutical industry involved in the production of sex hormones. Before these discoveries, the actual hormone could only be obtained from natural sources and its production was difficult and expensive.

The three discoveries described above all originated in academic laboratories, the first in the University of Toronto, the second and third in the laboratories associated with voluntary hospitals in London. They were all begun with the object of trying experiments, and not with a definite aim, and in that way they can be described as fundamental. The impact of these discoveries on science in general and on industry is, I think you will agree, very great indeed. There can be little doubt that what is wanted is the encouragement of fundamental research and that workers should have every facility to experiment merely for the sake of experimenting. It would also appear that the university or hospital laboratory is really the best place for this type of work to be conducted.

It is very important, particularly in chemistry and bio-chemistry, that money should not be given too cautiously. I think people ought to be allowed to run the risk of wasting money and not have to feel the whole object of their year's work is to prepare their annual report for the body which gives them the money.

Dr. C. D. Darlington, F.R.S.
The Unity and Power of Biology

What is biology? Is it everything from birdsong to the bacteriophage, from the bright red rose to the methylated and unmethylated anthocyanins? I think not. I think at least you want from me something that looks smaller than that, something more compact. But is there any compact version of biology? Someone has recently been asking (in America) whether such a thing exists. If you will allow me to go back to the beginning I think I can show that it does.

The impulse that set modern science on its feet in 1660 was the belief in its unity and its consequent power. The unity of its method was intellectually gratifying to some. And it gave a power in producing results which was economically gratifying to others. It gave also to a unity of theory. But that unity, achieved by Newton for physics and by Lavoisier for chemistry, was long wanting in biology. Among living things disunity triumphed everywhere. The only universal generalisation in biology in its first 200 years was that all living things were different. As Lamarck put it, properly enough, in 1804, ' Il n'y a réellement dans la nature que des individus.' The whole study was overwhelmed by the diversity of species. Some departments of biology are still overwhelmed by it. As a professor in my university recently told me : ' The different branches of biology speak different languages.' True enough. ' And,' he continued, ' they always will do so.' We shall see about that.

The first great step in bringing biology together was taken by Darwin in 1859. The theory of evolution made possible a cohesion between every part of the study of living things. The unification was not sudden or complete. The cement is still infiltrating the remote cracks and crevices of the subject and every year witnesses new instances of its effects, instances to which I shall return later.

But even while Darwin was at work the foundations of an entirely new structure were being laid deep down below him. We may represent these foundations by three disconnected discoveries. The first was the discovery by Mendel in 1866 that heredity depended on particles which did not mix or blend, permanent atomic particles carried by the germ cells. The second was the discovery by Hertwig in 1875 that it was the nuclei of the germ cells which had to fuse if fertilisation was to be accomplished, that the nuclei were therefore the essential agents of heredity. And last (in sense, though not in time) there was the discovery by Miescher in 1871 of what we now call nucleoproteins in animal cells.

It has been the work of this century to put these three discoveries together. We can now tell that the particles which Mendel inferred lie inside the cell nucleus whose movements Hertwig followed. And we can show that they consist of the nucleoproteins that Miescher isolated.

These nucleoproteins are so called because they have characteristically in combination with them nucleic acid. This nucleic acid gives them the unique power of reproducing their like which is the essence of growth and reproduction as well as of heredity. These three, always hitherto separated in biology, become at last aspects of the same chemical organisation.

Now nucleoproteins exist both inside and outside the cell nucleus. But the dominant part in heredity is taken by those inside the nucleus, that is by the chromosomes. It is only these chromosomes which have the mechanically fixed structure necessary for the control of something so permanent as heredity. Just as a legally fixed constitution is necessary for the government of a country so, it appears, a mechanically fixed constitution is necessary for the government of a cell and an organism.

These chromosomes we can see under the microscope. As nucleoproteins we can subject them to all the tricks of chemical and physical analysis. And as strings of genes we can change or recombine them in breeding experiments. Never before have three such entirely different methods of attack been brought to bear on one kind of structure. And when you remember that that structure

is the material foundation of heredity and development, equally in plants and in animals, you will see what a revolutionary change has taken place. The synthesis which has made plant and animal science into one has also made them one with physics and chemistry.

The theoretical consequences of this change have been quickly appreciated. In a recent book by Professor Erwin Schrödinger, the physicist describes this union as the most 'interesting' event in modern discovery. He points out that the chromosome molecules 'doubtless represent the highest degree of well-ordered atomic association we know of,' and that this property enables the organism, as it were, to live outside the world of increasing entropy around it and to escape to a very large extent the quantum indeterminacy of inorganic matter. We can no longer skip merrily (as some did a short while ago) from quantum mechanics to free will. The organism now has a say in the matter.

This theoretical union is, as always, intellectually gratifying. But what about its practical and technical effects? The wave of advance is moving outwards in all directions. I will give three examples.

Our knowledge of the chemistry and mechanics of heredity is gradually enabling us to control it. With X-rays we can break up the chromosomes and shake up the genes within them. We can combine, separate and modify nuclei by chemical and physical agencies. We can compress a millennium of variation within a few minutes, and by these means cross species that were once uncrossable and make hybrids fertile that were once sterile. In such ways as these plant and animal breeding have acquired the new strength they need to meet new tasks.

What these new tasks are we find when we take a second direction, that of disease. The study of disease has hitherto been split between medicine and agriculture, between plants and animals, between bacteria and viruses. It is now possible for biology to join together what specialised technology has put asunder. In the normal cell there exists, as we saw, nucleoproteins which reproduce themselves. Now viruses, so far as they are known, are nucleoproteins. They are capable of being extracted from the cell and even crystallised. And, since new viruses can arise spontaneously or in plants by grafting, it seems likely that in general they owe their origin to the introduction of the proteins of one plant (or animal) into the cells of another, or to the mutation of proteins already there. For viruses, like the genes of heredity, undergo mutation, selection, and therefore adaptation.

We have thus discovered a secondary source of life and evolution beginning at the molecular level. We have also discovered the evolution of one side of disease. On the other side, that of the victim, there is also adaptation and evolution. We know more of it in plants than in animals or man because plants are more easily experimented with. But the principle is the same everywhere.

Disease has a lock and key mechanism. Every victim is a lock into which the key of disease has to fit. Every species of victim is continually, under pressure of natural selection, changing the design of its lock. And every disease, also under pressure of natural selection, is changing the design of its key. In nature some kind of balance is kept up in this way. But see what happens in modern agriculture. Here the stock or the crops, the potential victims, are standardised for the use of man. In many of our crops a single individual is propagated by grafts or cuttings. The whole situation is simplified—from the point of view of the disease. A standard lock is provided for the disease organism. For a few years it fumbles with its keys and then, sure enough, it finds one that fits. And when it fits not one victim falls but a million.

This is the recent disastrous history of many crops, such as strawberries, raspberries, and potatoes, with the most advanced agriculture. It has been one reason why people have been telling us to give up advanced agriculture (or at least to give up the use of fertilisers). The remedy of course is to unstandardise our crops, a process which is fortunately not difficult to do if there are enough plant breeders.

For a third example let us turn to man and take what can be regarded as at once the most fundamental and the most practical question in biology, that of cancer. The cancer problem exists at different levels, every one of which is touched by the development of fundamental biology. First, there is chemically induced cancer which can be imitated by a chemically induced mutation, by a genetic change. Secondly, there is virus-induced cancer which can be imitated by grafting in plants. Thirdly, there are the special conditions of rapid cell division, abnormal chromosome behaviour and cell chemistry characteristic of malignant growth which can be imitated both by genetic changes and by chemical treatments in plants and animals. And beyond all these there is the great problem of the treatment of cancer by X-rays and radium—a problem whose solution is being reached by applying the principles derived from normal plants and animals suitable for experimental treatment. New theories and new techniques have sprung up from these foundations, and in consequence the diagnosis and treatment of cancer has been radically improved even in the past year. This improvement in turn will be passed on to many fields of medical practice.

It may well be said that biology as I have described it is not taught to-day in this country. That is true. Fundamental biology does not exist either for the botanist or the zoologist, either for medicine or for agriculture. Biology teaching and research are thirty years out of date. And for that reason the immense fruits of this unity and power will not be reaped for many years to come. Those who undoubtedly speak different languages may long continue to assert, in the isolation of their innumerable learned societies and research departments, that no common speech will ever be discovered, or ought ever to be discovered, in biology. To quote another professor in my university: 'We teach botany to people so that they can teach botany to people, and there is no point in making it more difficult than it is.'

But that point of view is being swept away. From what we see of different modes of activity of proteins common principles are emerging. And these common principles are as useful as they are fundamental. They give a power, both intellectual and material, a power that will, as soon as it

is allowed, make life look and feel very different for us all.

Dr. D. P. Riley

X-rays

A SINGLE fundamental discovery may have in it the seeds from which spring undreamed of advances in several branches of science as well as considerable technological application. At the time of the discovery these developments may be entirely unforeseen, yet they may turn out to be of the greatest importance. The development of scientific techniques involving the use of X-rays illustrates this point strikingly. Their impact has been felt in fields as widely separated as metallurgy and biology, or physics and clinical medicine.

The average person is well aware of the power of X-rays to penetrate a large number of solids. He has seen shadowgraphs of parts of the human body—he may even have been 'mass-radiographed' himself. It is clear that radiology is a powerful diagnostic weapon for the clinician, and it is now being used on a very large scale in the fight against tuberculosis. Similarly, radiology is important in industry for testing for defects in metal-castings, and for hundreds of similar tasks, among which we may mention the inspection of oranges, telegraph poles, motor tyres and packaged goods of all kinds.[1]

However, the importance of X-rays in fundamental science lies not in radiology but in X-ray diffraction, a quite different thing. I shall not attempt to explain X-ray diffraction but I shall review why we consider it so important. X-ray diffraction enables us to discover the arrangement and sizes of atoms in solids and, to a lesser extent, in liquids and gases also. It is as if we had a terrifically powerful microscope which enabled us to see the actual atoms which make up a solid. We are able to measure their size and we can see how they pack together in space. In short, X-rays provide a yard-stick for chemistry. Modern chemistry is a precise and metrical subject and the X-ray crystallographer has helped to make it so. Modern chemistry is three-dimensional; no longer are we satisfied in writing down molecular formulæ on a flat piece of paper. We make up a model in which the exact distances apart and distribution of the atoms in space are clearly shown. X-rays have enabled us to map molecules in three dimensions. The precision thus brought to structural chemistry has given us a great deal of insight into the general laws which govern chemical combination. From tables of atomic radii we can predict the size and shape of molecules, from tables of bond energies we can predict weak links in the molecule or say something about its reactivity. Other methods, notably that of infra-red and ultra-violet spectroscope, have also been of the greatest use in this latter connection.

X-ray diffraction is, then, an analytical tool of increasingly great power. By its aid we have found out exactly where the atoms are in most of the simpler chemical substances. We can classify elements and their compounds into various structural types and effect some correlation with their physical and chemical properties. In recent years the X-ray worker has become more ambitious and has been examining the complex structures of biological importance: hormones, proteins, viruses. The foundation for this work was laid before the War by Bernal, Miss Crowfoot and Fankuchen, and undoubtedly great advances can be anticipated. Dr. Astbury has already described the work on fibres such as wool and hair and also on animal tissue and muscle. Plastics have been intensively examined and a great deal of knowledge about their structure has been obtained. The cause of rubber-like elasticity is known. The important cellulose fibres have received a great deal of attention as has the related but more difficult problem of the structure of starches. The modern tendency is to enlist the aid of X-ray diffraction at the very outset of an investigation into the structure of a new substance or material. In a number of cases valuable information is rapidly forthcoming which is of great help to the chemist proper. This is particularly the case with the more complex organic molecules. Indeed, in some cases (e.g. the sterols) the crystallographer has been able to show that the accepted molecular structures were incorrect and to guide the chemist on to the right path. This close collaboration between the chemist and the X-ray crystallographer is becoming a common feature of investigations into complex structures and during the war has produced some startling results.

One must mention, too, the new mineralogy founded on the X-ray structural investigations of the Bragg school. Previously, the chemical constitution of the silicate minerals was something of a puzzle. It was impossible to think of a structural scheme in which to fit them. The work of W. L. Bragg, W. H. Taylor and their colleagues provided a complete answer. The atomic positions in these complex structures are completely known and it is now seen how the large number of different silicates fall into a small number of structural types.

To pass from chemistry to physics—X-ray diffraction has helped us to a much deeper understanding of the physics of the solid state and, in particular, of metals and alloys. The fundamental aim in this work is to relate the properties of the solid—such as hardness, elasticity, ductility, thermal and electrical conduction, magnetism—to the underlying atomic arrangement. For obvious reasons this work has concentrated mainly on the metallic state. The crystal structures of all the important metals are known with great precision, as are those of a large number of alloys. It is not too much to claim that metallurgy has been revolutionised by these findings. This is not to say that the classical metallurgical techniques have been superseded, but it is true that a metallurgical laboratory needs an X-ray outfit just as much as it needs a microscope. The ordinary microscope can only distinguish particles or regions of size greater than about 10^{-4} cm. and usually particles have to be much larger than this to be distinguished. It is the gross structure of the metal that is examined. This information is richly supplemented by means of X-ray diffraction which takes us down to the scale of atomic dimensions (10^{-8} cm.). We can distinguish the crystal structures of the various phases in an alloy and estimate their grain size, and the sizes measurable by X-ray diffraction are 10^{-5}–10^{-8} cm. This size range has

[1] J. A. Crowther (Editor), *Handbook of Industrial Radiology*, London, 1944.

also been investigated in recent years directly by means of the electron microscope. We can also see whether the crystal lattice itself has been deformed by the treatment the metal has undergone. A great deal of light has been shed on such important problems as hardening, age-hardening, cold work, strain and so on. There is still a long way to go, but a fundamental physical interpretation of metallurgical properties is being built up and already had proved of the greatest practical importance.

Another aspect of the problem is that of the thermodynamics of the crystalline state. What exactly happens when a crystal is heated or compressed or strained? Starting only from a knowledge of the arrangement of atoms in the crystal and of the forces between the atoms can we calculate theoretically its properties? The answer is that in certain simple cases almost a complete picture of the behaviour of the crystal can be predicted. In this work the theoretical physicist has co-operated with the X-ray worker to their mutual advantage. A new subject of crystal dynamics has been created which is likely to prove of the greatest importance both to science and industry. The earlier X-ray crystallography has been mainly concerned with the geometry of the crystal structure: it tells us where the atoms are; the emphasis is on arrangement. The newer crystallography wants to do more; it wants to find out something about the movements of the atoms. In a crystal the atoms do not stay still; particularly at high temperatures, they are vibrating. By means of a new technique, largely developed in the Royal Institution, it is possible to discover the magnitude and direction of these atomic vibrations. This leads us directly to a consideration of the forces that hold the atoms together, and it is these forces that ultimately govern a large number of important properties such as strength, elasticity, specific heat, thermal expansion, compressibility, etc. Thus, hand in hand with the theoretical physicist, the X-ray crystallographer is now really getting a fundamental understanding of the solid state. It would be difficult to overestimate the potential importance of this work, and I would strongly urge that the maximum of material encouragement be given to those engaged in it.

X-ray diffraction methods are increasingly being used in industrial laboratories in a more or less routine way. One important application is the identification of crystalline material. Every crystalline solid has a characteristic X-ray diffraction pattern, and no two substances give quite the same pattern. Each substance has its 'X-ray fingerprint,' so to speak. Workers in the U.S.A., the U.S.S.R., and in this country are collaborating to prepare an index of the X-ray patterns given by a large number of common (and uncommon) substances. With its aid, one can rapidly identify the constituents in an unknown mixture. Furthermore these constituents are identified precisely—whether a salt is hydrated, for instance, is shown clearly. To give another simple instance: ordinary chemical analysis could not completely specify a mixture of NaCl and KBr; it would merely show the presence of Na, K, Cl and Br; it might just as well be a mixture of NaBr and KCl. But the X-ray method would identify the constituents as the crystalline salt, NaCl and KBr, and not merely as any conglomeration of the four elements. Such a method of analysis is of great use in connection with refractories, to name only one instance. Another useful application, which has already been mentioned, is the estimation of particle-size. This might be used in connection with carbon-black used as a rubber-filler, or in the study of catalysts. The orientation of the individual metal crystals in a drawn wire or rolled sheet is easily determined by X-rays. The stresses which a metal bearing has undergone can be estimated. Analogously, the preferred orientation of molecules in synthetic fibres or rolled sheets of plastic can be measured. New applications are being found every day and there is a great demand in industry and elsewhere for trained personnel capable of using this new technique.

The increase in applied science during the war has been particularly marked in the field of X-ray crystallography. Industrial and Government laboratories found that there was a wide range of problems capable of solution by this method, but few of these laboratories had either the necessary equipment or the personnel. There was a tendency in the first place, therefore, to consult the university X-ray workers. This was good for the university people and, I hope, not unsatisfactory for the industrial people. In the course of time, however, X-ray equipment was installed in more and more Government and industrial concerns. The obstacle now was that there were only a few people who had had a full training in X-ray crystallography. Inevitably, a number of physicists, or even chemists or metallurgists were suddenly presented with an X-ray outfit and an array of problems and called upon to give the answers. I do not know if the answers were always forthcoming, but good scientists are adaptable and ready to learn, and they learned. But it was made clear in certain conferences called by the Institute of Physics that the level of understanding was very uneven. Routine applications were being pursued with success, but anything out of the ordinary showed up the lack of fundamental training in the subject. These conferences were an attempt to pool ideas and techniques from the universities and the best industrial laboratories and have certainly helped a great deal. In addition we took the step in Cambridge of organising a summer school in X-ray crystallography for industrial scientists. A fortnight's intensive course has been given for the past two years to selected groups of X-ray workers. Both the fundamentals and applications of the subject are taught, and we have also tried to point the way forward so that some people may be inspired to break new ground. Quite apart from the pedagogic value of such a course, it has had the effect of creating close personal contact and understanding between the industrial and academic scientists concerned. We appreciate each other's problems and try to help each other. The contacts made have been kept up in a most encouraging way.

I believe that such summer schools should be a far more frequent feature of our scientific life. We have very little in the way of post-graduate courses at present and they are badly needed in some subjects.

Perhaps these remarks on X-ray diffraction have

helped to show some aspects of the relation of fundamental research to industry. But it is not enough that the universities should do the fundamental research and industry should apply it. I firmly believe that a very great deal more fundamental research should be done actually in industrial laboratories. We do not have the same attitude here as in the U.S.A., where fundamental or, if you prefer it, pure science, is actively pursued in a number of large industrial concerns. The American business men seem to have appreciated the need for fundamental research in their own concerns more than their British counterparts. Charles M. A. Stine,[2] Vice-President of E.I. du Pont de Nemours Company, says 'Why fundamental research?' The answer is clear; industry should learn to-day in order that it may be prepared for to-morrow. Thus there is an implied monetary motive for fundamental research in industry. To put it in another way, fundamental research in the technical laboratory is not a labour of love. It is sound business policy. It is a policy that should ensure the payment of future dividends.' He is very careful to define fundamental research. He does not mean 'pioneering applied research'—he means the sort of research we do in our university laboratories here. I have not heard a similar unequivocal statement from a British business man.

When strongly advocating a great deal more fundamental research by British industry, I would add one condition. The results must be published in the normal way; indeed, the scientist must be encouraged to publish. This is certainly not the case at present; too many firms still believe that 'silence is golden.' This over-caution, fear of competitors, or just plain obstruction, means that a considerable amount of valuable work carried on in industrial laboratories is never published. A sort of silent pall hangs over too many of our industrial laboratories and Government laboratories as well. What is not published is not science. The free criticism and discussion that comes of publication is the foundation on which all scientific advance is based.

[2] National Resources Planning Board, "Research—A National Resource: Part II—Industrial Research," Washington, 1940.

INDUSTRIAL RESEARCH AND DEVELOPMENT

SATURDAY, JANUARY 13: MORNING SESSION

ADDRESS BY LT.-COL. SIR JOHN GREENLY, K.C.M.G., C.B.E., CHAIRMAN OF THE SESSION

WHEN I was privileged to receive an invitation to take the chair at this morning's session, I visualised that I should be expected to behave like all well brought up children of the Victorian era, namely, that I should be seen and not heard. However, I was assured that it was customary for the Chairman to make a few opening observations, and I trust, therefore, that the brief time I am going to occupy will not in any way militate against your anticipated enjoyment of listening to the five distinguished speakers, who are going to follow me, each a master of his own subject.

It appears to me that the series of subjects for this present conference has been particularly happily chosen, for surely to-day there are few matters of more outstanding interest than the relations of science to industry, and, in particular, industrial research and development, the subject of this morning's session. We are indeed fortunate in having as our speakers Dr. Sykes, Dr. Hooker, Mr. Devereux, Mr. Swallow and Mr. Bacharach. Each will deal specifically with his own viewpoint, and perhaps therefore it will not be out of place if I make a few general observations on our subject this morning.

To those of us who have been impressed throughout our working lives with the value of science as applied to industrial problems, it is a little surprising to find in this year of grace, 1945, that there are still those who appear to doubt whether science does or can contribute to industry all that its protagonists claim for it. I have, in season and out, preached the doctrine of scientific research for the past thirty years, and never for one moment have I had occasion to waver from the view I formed early in the last war that science had contributed and would continue to contribute immeasurably to successful industrial enterprise. It seems to me that this has been proved over and over again, but none the less there are still those who hesitate in their own business to encourage scientific methods; there are still those who only half-heartedly support their Research Department, if, indeed, they have one, and there are many who, even to-day, are unwilling to contribute to the Research Association of their own industry. Such an attitude of mind is to me, after a fairly long experience of industrial life, quite incomprehensible. It ever there was a case of casting your bread upon the waters and finding it after many days, the application of science and scientific research in industry is that case. If anyone here this morning is not convinced of this by any remarks of mine, he will be a doubting Thomas indeed if he still remains of the same mind after listening to the speakers who follow me.

And this is no new conception that I am enunciating. Marcus Aurelius, Emperor of Rome from A.D. 161 to 180, had quite a

clear idea on the subject. In his Third Book of Meditations he wrote : ' nothing has such power to broaden the mind as the ability to investigate *systematically and truly* all that comes under thy observation in life.' I would call your attention particularly to the words ' systematically and truly.' Surely that is exactly what we ask and get from science to-day in its application to industry. It is true that the great Emperor apparently did not hold quite so high an opinion of the geologist, if we may judge from another quotation from his Second Book—' Nothing can be more miserable than the man who goes through the whole round of things and pries into the things beneath the earth.' But Marcus Aurelius, none the less, would have thought highly of the Coal Survey, had it existed in his time, for surely there was never a better example of the value of scientific investigation and development as applied to one, and perhaps the most important, of our basic industries.

And now may we for a few minutes consider what are the main contributions that science can make to industrial research and development ? I said, ' for a few minutes,' but if one considers for even one minute, it becomes evident that science has almost no limitation to its contributions in this sphere.

First and foremost, perhaps, comes the contribution of new ideas, and prospects arising from fundamental research, and leading on to new inventions. Examples of such instances are so numerous, and so well known, that it is unnecessary to enumerate them to-day.

Hardly less important is the continuous help that science can give to the normal conduct of a business by indicating improved methods of production, and suggesting the use of new materials. It was said that ' engineering is the art of doing that well with one dollar which any bungler can do with two after a fashion.' How much more true is that statement if applied to science in its contribution to industrial development.

I would like to cite one particular example of what I mean. Before 1914, the art of welding was in its infancy and was regarded as a method of repair rather than a primary manufacturing process. Welded structures were viewed with suspicion, and the whole idea was looked upon as being as new-fangled and unreliable as the motor car was in, say, 1900. It is true that forge fire welding had been practised for many centuries, but metallic-arc and oxy-acetylene welding did not become primary processes of much importance until after 1918.

The most noticeable step forward in the development of welding was made possible by the application of the scientific knowledge of the electric arc, the properties of flames, and the deeper understanding of metallurgy. This in due time, was followed by an even greater advance—the application by the scientists of X-ray technology as a means of determining the soundness of welding technique and weld quality. To-day, thanks to the continuous application of science to the problem, and the unremitting help which scientific thought and experiment has contributed, welding has become an accepted method for the manufacture of highly stressed structures required to withstand arduous service conditions. In ships, military tanks, aircraft, ship machinery, automobiles, bridges, heavy machinery for electric generation, and heavy pressure vessels of all types and size—in all these, welding is freely and successfully employed, and thanks to scientific research and its development, we can to-day weld together steel plates up to 6 in. in thickness with the certainty of success.

I have especially cited the case of welding because it appears to me to illustrate so well an instance where science has helped to make an industry more efficient, has given us a new and a better technique, and, in consequence, has assisted in helping us to solve the problems of export and full employment. I doubt whether in the post-war world any problems will give us more cause for anxiety than these two. And yet I suggest that science, properly applied to research and development in industry, can contribute much towards the solution of these closely allied questions.

One of the speakers at yesterday's conference stated that he felt he did not want better things but more of them, more cheaply made and more rapidly, and he suggested we did not want better radios and better refrigerators but more of them, so as to benefit our people as a whole. I think we would all agree with that, but we ought to bear in mind that nothing but the very best will do in regard to the export world, and I think it is important that science and scientific methods should be applied to improving the quality of our exports even though possibly the less good will do at home.

Sir William Beveridge has told us that up to now it has always taken a world war to provide full employment in this country. That may well be true, and I am beginning to think it requires the same thing to bring home to us the proper appreciation of scientific achievement. Certainly nobody will deny for one moment that the scientists of this country, by their outstanding achievements, have played a major part in securing the certainty of the longed-for victory which is now in sight. Can they not equally, if the

opportunity is given them, contribute to the winning of the peace which lies ahead, and by their co-operation in industry, help that rehabilitation of our industrial life, and the full and lucrative employment of our people, which we all have so much at heart? I, for my part, believe they can, and I see no reason why the outstanding scientific advances of the wartime years should not be continued when peace is with us again, provided we make sure that scientific endeavour is given equal encouragement and opportunity in peacetime as it has been given in the time of peril.

And now I would like to say a word as to what makes it possible for science to be of such help to industry, apart from the skill and knowledge of the scientist himself. I believe it is summed up in the word 'co-operation.' Scientific research and scientific development cannot be successfully achieved in industry without full co-operation on the part of all concerned. Responsibility lies both with the scientist and with the producer. If it is the responsibility of the former to solve the problems that are set him, it is most certainly the responsibility of the latter to bring those problems to the scientific staff of the organisation, and to help that staff in every way to achieve those objects that both sides should have in view—the improvement of technique, the more efficient control of production, the introduction of new and better materials, and testing and perfecting of new inventions. The whole process must be approached with the team spirit uppermost in the minds of both the scientific and production staffs. Otherwise, failure, disillusionment, and disappointment will result. One unconvinced industrialist of the non-receptive school can go a long way towards discouraging any progressive young scientist in his business if he sets his mind to it. We must however, remember that the final responsibility as regards production lies with the engineer, and in consequence, it is all the more important that he should approach his problems with a broad and open mind, and see to it that the best possible use is made of the scientific staff at his disposal.

And that leads me to one further thought. It not infrequently happens that during the course of an investigation into some problem, the scientist may catch a glimpse of some entirely new possibility scarcely connected with the immediate task he has in hand, and yet offering the promise of some fresh line of development which may prove of great value to the business. Let us be sure that he is given an opportunity of pursuing that first glimpse; that at a suitable time, when the main problem has been solved, he is encouraged to follow the line which that fleeting thought may have engendered. It is by such means that great inventions have been achieved and great results obtained. As a friend of mine, who has done more than most men to encourage science in industry in this country, said to me the other day: 'The scientist is in a sense the path-finder in industry.' That is very true, but it is up to the management of our industrial organisations to see to it that the scientist is given, not only the means, but also the moral backing, to follow those paths even if on occasion they end in an apparently impenetrable jungle. Not infrequently, they will lead through the morasses of doubt and the tangle of the lower slopes to the open uplands of great prospects and high achievements.

Dr. C. Sykes, F.R.S.

In dealing with the inter-relation of research and development one is faced with the difficulty that no hard and fast line can be drawn indicating where research ends and development starts; the research stage and the final development are clear, but there is an interval between the two which is a combination of both.

Broadly speaking, one function of an industrial research laboratory is to discover new and improved products and processes. The impetus and ideas underlying such activities will arise in the laboratory, or by contact with and suggestions from sales and production departments, and from customers. Outstanding ideas which lead to considerable extension and possibly to the formation of new industries are relatively few and cannot be produced to order. I have in mind such developments as the gas turbine, stainless steels, carbide cutting tools, steels for high temperature service, low vapour pressure oils, etc. Such discoveries usually await the association of a particular individual with a favourable set of circumstances, and the research organisation can best assist by providing adequate facilities for research and the right atmosphere. The elaboration and application of outstanding ideas supplies the incentive to large groups of research workers over very long periods.

We may expect, then, from the industrial laboratory recommendations relating to improved products and processes from time to time, and occasionally major discoveries involving new principles originating either internally or from the field of pure science. These recommendations will be based on a limited amount of experimental work, the results of which are considered to justify an extended investigation. For the purposes of this discussion it is convenient to define this initial stage as the research stage and to define as development all the subsequent work necessary to place the new product or process on a routine commercial basis.

The development phase has a variety of problems of its own and is usually more costly both in time and money than the initial research stage. It will be clear that the problems vary greatly in character, depending on the type and scale of the

development under consideration. It may concern a product which is very similar to an existing one ; here the problems are usually simple if full account is taken of the available manufacturing experience. In the case of an entirely new product new manufacturing processes and plant will be necessary, and the general experience of the production departments must be supplemented by additional research data as difficulties develop. For economic success, certain developments must be carried out on a very large scale or not at all, consequently large sums of money must be risked on theoretical estimates from small pilot investigations. Indeed, it is fair to say that every single development presents its own peculiar problems.

Nevertheless, there are certain principles of general application. Clearly as much information as possible should be obtained at the small scale level since this avoids premature large scale expenditure and minimises the risks. There is a natural desire to bring developments to a commercial stage as quickly as possible—and it is one of the functions of the research man to make sure that all reasonable precautions are taken to avoid premature decisions. In this connection, he has to adopt a Jekyll and Hyde attitude towards his own work ; an optimistic outlook is essential for success in his laboratory, but he must rate his actual achievements very soberly, otherwise disappointment is inevitable sooner or later.

At the earliest possible stage, it is desirable to consult the production departments likely to be ultimately concerned with the development. The research side tends to underrate the value of experience and may forget that certain operations which may be perfectly reproducible in the laboratory can be impracticable commercially. Alternatively, the production expert is by nature conservative and tends to overrate the value of experience. By collaboration at an early stage arrangements can often be made to suit the processes being evolved to the plant and technique already available. This seems an obvious point ; but much time has been wasted in the past, and will no doubt be wasted in the future, owing to lack of adequate collaboration.

Once the manufacture of a product or the operation of a new process is started in the works a new set of factors has to be taken into account. A different type of labour with its own peculiar advantages and limitations has to be used, processes must be worked to a definite schedule, and frequent modifications in the schedule cannot be tolerated. The active control passes from the research worker to the works personnel.

Here the limitations in the available knowledge are revealed, since for adequate works control far more information is required than is usually available. Very often, of course, this state of affairs cannot be avoided, and practice is developed as the experience accumulates. It should be recognised that works control is not vitally concerned with the reasons why a particular operation produces a certain result, but rather with the maximum tolerance in the variables defining that operation, within which a satisfactory product will be produced. Useful work in the development period is devoted to evaluating these tolerances, and this often involves the deliberate production of unsatisfactory material. It is usually found that whilst many of the individual operations in a process of manufacture can be carried out successfully in a variety of ways, others have to be controlled quite carefully. Such information not only enables a reliable process schedule to be drawn up, but also provides a sound basis for flexibility in operation of plant, etc.

It will be deduced from the preceding remarks that the research man engaged in development requires a somewhat different outlook from that of the pure research worker ; his suitability should be judged not by his intrinsic ability to produce new ideas but rather by the skill displayed in producing sets of rules and straightforward operations which when turned over to works operators provide results of a satisfactory consistency. Similarly, no doubt it will be agreed that the personality of the development man is just as important as his technical qualifications, since the rate at which development proceeds depends to such a large extent on the degree of confidence he can establish with the production side, and the pertinacity with which the minor difficulties and setbacks are tackled.

All development work is carried out with a view to satisfying either some demand that exists or a demand which it is thought can be created. Of necessity, the decision as to whether a new product will be suitable or not for its proposed application has to be made frequently on the basis of a variety of short-period type tests. Since it is impossible to cover completely all the factors involved in actual service in this way it is desirable at an early stage to issue the product to some interested user and get his opinion and advice. He will very often discover faults and make valuable suggestions for improvement which have escaped both the research and development personnel, since the latter can seldom be familiar with the detailed service conditions. The collaboration between user and supplier is not the least important phase of any successful development.

The length of time required for a development of reasonable importance is measured in years ; in normal times, for example, five to ten years will be necessary thoroughly to establish a product embodying a marked degree of novelty, and only towards the end of the period will profits overtake the rate of expenditure on development. Throughout the whole of this time keen and active interest has to be maintained to prevent any minor fault from reacting unfavourably and putting the whole development under a cloud.

So far I have been concerned with considerations which may apply equally well to any industry. Research and development in the ferrous metallurgical industry is characterised by certain problems in an exaggerated form. Certain of the melting and manipulating processes are now carried out in very large units for economic reasons. Further developments in the direction of further economy involve very large capital expenditure. Whilst research can provide basic technical data indicating the directions in which progress can be made, other essential information for the justification of such development expenditure—location of possible markets, variability in demand, price control, etc.—is far more difficult to formulate. Successful large-scale develop-

ments both in metallurgy and in other industries therefore reflect great credit on the courage and enterprise of the organisations concerned, as well as on their technical ability.

The important mechanical properties of metals and alloys cannot be predicted *ab initio* from knowledge of their chemical composition. The great bulk of metallurgical products have therefore been developed empirically to suit their particular applications, and this has led to the accumulation of a great deal of data and experience which covers existing practice. In making this statement I do not wish to minimise in any way the achievements of pure science in metallurgy. But they have been rather in the nature of explaining results which have been produced empirically. This of course is a valuable service, and helpful, because it enables us to understand what we are doing and solve problems of a similar character at a much more rapid rate. We are, I think, coming to the stage when pure science will be able to help us a great deal more, i.e. when it may be possible to determine theoretically more about the properties of metals. In the meantime, however, metallurgists must continue to employ the various improvements in technique and knowledge which come to hand from time to time, in order to reduce the work involved in the search for better materials to a minimum, and hope that further developments in pure science will come along to simplify their task.

There are certain applications for metals in connection with which the engineer is able, as a result of experience and calculation, to specify just what he requires in terms of the measured physical properties usually available. In a great number of cases, however, the service conditions are so complex that he must proceed with his selection by trial and error.

A consideration of the operating conditions of such devices as the tank, sparking plug, cutting tool, heat-resisting and corrosion-resisting plant, etc., will show why this is so. Laboratory tests in such cases can only be expected to give a general indication of behaviour in service. Where service life is long, trial and error methods consume a good deal of time, since lack of knowledge of the controlling factors is rightly associated with an increased amount of conservatism. Thus, many metallurgical developments involving new materials take place very gradually, owing to the slow rate at which records of service performance can be accumulated.

Whilst other examples could be given, enough has been said to indicate some of the special features associated with metallurgical research and development; no doubt factors of similar importance but somewhat different in type operate in the other major industries.

Recently, leading industrialists and economists have emphasised that in the post-war period the industry of this country must expect to find its world markets primarily in new and modified products. Both our pre-war and war record with regard to major developments will bear comparison with that of any other industrial nation; nevertheless it is clear that to keep abreast we should take all reasonable steps to stimulate new developments. How is this to be done?

A study of our war experience shows how rapidly developments can be brought about under special circumstances, and suggests attention be given to the following factors.

We need to consider the present allocation of our technically trained personnel and at the earliest moment feed some of it back into industry. During the war years the recruitment of technically trained young men has been negligible in many industries. and many industrial research workers have moved out either into the Services or to executive positions. Similarly, the schools for research and training at our Universities are very much depleted and special attention should be given to the problem of building up them as rapidly as possible. We need the trained personnel, the fundamental research and the new tools which such institutions provide.

Our many periodicals, both scientific and otherwise are filled with appreciations of what scientific research has done. We should reward its achievements by something more concrete than lip service. Adequate funds should be made available for pure research, and industrial development should be encouraged. In this latter connection the recent official statements relating to reduction of taxation on industrial research are welcomed.

Every industry both consumes and produces, and in the long run a major development in one industry reacts favourably on industry as a whole. Greater realisation of this would help to improve the collaboration between industries and thus accelerate the rate of development. In this way, the principle of "operational" research, which has proved so profitable in war, can be carried over into peacetime research.

Dr. S. G. Hooker

The Development of the Merlin Engine[1]

THERE comes a tide in the affairs of any engine when the question arises: 'Shall we proceed with the development of this engine, or shall we design a new engine to replace it?' In the case of the Merlin, this question arose early in 1938, and was brought to a head by two main considerations, the first being whether the Merlin could develop reliably sufficient power for the newer and larger types of aircraft which were envisaged at that time, and secondly, would the Merlin be at a disadvantage to the two German engines, namely the Daimler Bens 601 and the Junkers, which were, in fact, each roughly 25 per cent. larger in capacity.

The decision taken was that the development of the Merlin engine should have priority over everything in the Rolls-Royce factory, and that as an insurance policy a larger engine, the Griffon, should be designed. Little did we know at that time the great issues which hung on that decision, or the great successes which were to arise from its fulfilment. Two years later every fighter that fought in the Battle of Britain was to be powered by a Merlin engine, and this same engine was to be fitted to almost every first-line British aircraft. On the fighter side it is fitted to all Hurricanes, Spitfires, Seafires, Defiants, Mustangs, Mosquitos, Barracudas and Fulmars, and in small quantities

[1] This is a summary of a communication illustrated by models, slides, and films.

to the Beaufighter, while in the bomber class it is in service with the Battle, Whitley, Lancaster, Halifax, and in small numbers with the Wellington.

The Merlin has been produced in this country and in America in larger numbers than any other aircraft engine, and on an average more than one million Merlin h.p. has gone forth each week, throughout the five years of this war, to strengthen the allied air forces.

The Merlin engine started life in 1932 with three great assets—namely, (1) the basic 12-cylinder liquid-cooled type had an unbroken lineage extending back to the Rolls-Royce Eagle engine of the last war; (2) it had the guiding hand of Sir Henry Royce in the design stages, although he did not live to see the first engine run; (3) the development experience gained during the last three Schneider Cup races, when finally a Rolls-Royce R engine of 1,630 lbs. weight produced 2,530 b.h.p.

In the development of the Merlin, therefore, the problems met with fell roughly into three categories: (*a*) problems of vibratory stresses with their attendant fatigue failures; (*b*) problems of heat flow, with their attendant valve, cylinder head and piston failures; (*c*) problems in the improvement of performance, both at sea level and at altitude.

I have omitted above any mention of materials, because it is taken as a *sine qua non* that these are above reproach, thanks to the severe inspectional checks to which all Rolls-Royce materials are subjected. Despite this, naturally, defective parts creep in, and improvements in the inspection procedure are continually being introduced. As the latest example, I have with me to-day the Supersonic Flaw Detector, which has been loaned to me by the courtesy of Mr. D. A. Oliver, Director of Research of William Jessops, Ltd. This apparatus is akin to the submarine detector, and is capable of finding flaws and cracks beneath the surface of a steel forging. It depends upon the echo which is reflected from any flaw in the path of the supersonic rays, and by the size and position of the echo wave on the Cathode Ray tube it is possible to determine the position and size of the corresponding flaw.

In the realm of material inspection also, a new technique for examination of aluminium castings and forgings is coming into use, namely, that of X-ray diffraction. This technique is used for the detection of internal stresses locked up by the forging and casting processes, which can lead to failures when the normal engine stresses are superimposed thereon.

I now pass to the field of vibration and alternating stresses, which lead to fatigue failures in a running engine. One of the most highly stressed parts of the Merlin engine at its present high powers is the connecting rods, which are subject not only to direct compressive and tensile loads, but also to an alternating bending stress due to the reciprocating motion.

Catastrophic connecting-rod failures were not unknown in a Merlin engine at one time, and in the examination of this problem we called to our aid a photo-elastic investigation. By a modification in the shape of the rod, the stress concentration at the point of failure was considerably reduced, with marked beneficial results to the engine.

It will be readily appreciated that if one could only see the parts of an engine under working conditions, then many of the mysterious happenings would be made clear, and a new aid has now come forward in the form of the high-speed cinematograph camera. A film of the Merlin cam shaft and valve-operating mechanism was taken at a rate of 2,000 exposures per second, whilst the engine was running at a speed of 3,150 r.p.m. The cam shaft of a 4-stroke engine goes at half engine speed, so that in this particular case it was rotating at 26 revolutions per second. Consequently some 77 pictures of its motion and that of the valve gear were taken during one cycle of its operation. The film shows the manner in which the cam shaft rotates in jerks as each valve is depressed, and it can be seen from the motion of the top valve spring washer that the inlet valve bounces off its seat on closing, this bounce not being consistent with every stroke, but being sometimes much greater than at other times. The surging of the valve spring is also apparent and explains many mysterious valve spring failures. As a result of this work the cam form of the standard cam shaft has been altered from a constant acceleration to a parabolic acceleration form. This has reduced the "flick" on the cam shaft and has improved the wearing qualities of the rocker pads and the valve gear. An analysis of the motion has shown that the 'flick' is directly controlled by the stiffness of the cam shaft and its driving shaft, and the backlash in the driving gears, since there is no resonance in the system. All of these features have undergone a steady improvement as a result of this cinematograph study.

In judging the merits of any development modification to an engine, the final acid test is the Air Ministry's specified type test, and from experience we know that if an engine will complete this test successfully its reliability in service will be sufficient. Consequently endurance running under type test conditions forms a large part of any engine development programme; but in certain cases it is possible to speed up the reproduction of failures by running the engine for short periods under special conditions such as, for example, high power and high revolutons per minute. When a new rating of the engine is considered, therefore, it is our custom immediately to start continuous endurance running at the maximum load condition. The success of a development programme of this nature depends to a large extent upon a logical deduction of the cause of the failures and a careful choice of the methods of rectifying these. As an example of this, we have slides showing a number of parts of the engine which were modified as the results of experience at 3,000 r.p.m. and 18 lbs. per sq. in. boost pressure, and attention may be directed particularly to the modification of the piston illustrated. This consists of a deletion of the top scraper oil ring and a wider spacing of the gas sealing rings, the object being to avoid the gumming and sticking of rings during running. It will be appreciated that the effect of gummed piston rings is very serious inasmuch as the attendant blow-off of hot gases causes failure of both piston and the cylinder liner. This modification was a particular case of careful, logical deduction from the results of tests and

depended upon the not too obvious hypothesis that the important variable was the strength of the metal bands between the rings.

War conditions require an ever improving aircraft performance, and the progress of any aero engine is judged solely by the increase in power which it can produce. I do not mean by this that reliability is secondary, but merely wish to indicate that no air force can retain its superiority solely by an increase in the reliability of its engines.

The power output of a supercharged engine depends upon the pressure in the induction pipe or boost pressure as it is termed, and this pressure is controlled automatically by the throttle so that the pilot cannot exceed safe conditions. The boost pressure which an engine can stand is limited by the detonation value of the fuel. The effects of detonation upon an engine are catastrophic and in a few minutes under detonating conditions the cylinder head and piston crown can be completely ruined by the hammer-like blows of the detonation wave.

The onset of detonation can be controlled both by the richness of the mixture (i.e. the charge temperature) and by the type of fuel, the latter being by far the most important. Using the 100 grade octane at 1,000 h.p. at maximum economical mixture detonation just begins, but it can be suppressed by richening the mixture. At 1,450 h.p. no further richening of the mixture helps, and consequently this is the limiting power. British fuel technologists, however, have produced the 150 grade fuel, and by this means powers up to 1,800 h.p. can be obtained free from detonation, a striking advance when you consider that 100 octane fuel was comparatively new at the beginning of the war.

The boost pressure on an engine can only be controlled by the throttle up to the full throttle or critical altitude. At this point the throttle of the engine is wide open and the engine develops its maximum power. At higher altitudes the induction pipe pressure falls owing to the decrease in atmospheric pressure, and with it the power of the the engine. Consequently the full throttle power of the engine depends solely upon the efficiency of the supercharger, and its capacity to maintain the induction pipe pressure. In 1939 we were operating on the engine with supercharger compression ratios of between 2 and 3 : 1 and efficiencies of between 70 and 60 per cent. During the period immediately following the Battle of Britain the German fighters found that they had a superiority at high altitudes owing primarily to the very light weight of the Messerschmitt 109 fighter, and consequently we introduced the Merlin 46 Supercharger to improve the Merlin performance at high altitudes. This supercharger operated at between 3 and 4 : 1 compression ratios with efficiencies of between 75 and 70 per cent. This improvement over the Merlin III was achieved by a re-design of the entry and the impeller, the design being guided by a careful mathematical analysis of many supercharger rig tests.

At this time, however, we realised the great benefits which the 2-stage supercharger with an intercooler would give, and consequently this project was put in hand. By its use we were able to operate on the engine with compression ratios exceeding 6 : 1 with efficiencies exceeding 70 per cent. and at the same time by use of the intercooler we were able to control the charge temperature to any prescribed value. This 2-stage supercharger has been one of the most important power developments on the Merlin engine, for not only did it enable sea-level pressure to be maintained in the induction pipe up to 40,000 ft. altitude, but also it enabled us to increase our boost pressure at sea level owing to the ability to control charge temperature.

With a large wartime programme on hand, the advantages derived from the development of a standard type of engine are enormous. As a result of Merlin development, all Rolls-Royce factories with their innumerable sub-contractors have been able to concentrate solely on the production of one type of engine throughout the war. Consequently expensive jigs, tools, fixtures and special machine tools have been multipled and improved indefinitely without fear that they would be scrapped before their utilisation has been reached. The same benefit is passed on to the aircraft manufacturer who can also lay out his programme on an extensive scale with the confidence that improved powers and reliability will mature.

The force of this argument is brought home when one considers what must have happened in Germany when the change-over from the Messerschmitt to the Focke-Wulf fighter took place. Here we have a case of a country laid out to produce in enormous quantities the Messerschmitt fighter with the liquid-cooled Daimler Bens 601 engine. The ramifications of this programme were spread all over the German industry, and yet in the middle of the war both the aircraft and the engine were replaced by the Focke-Wulf fighter and the MW air-cooled engine. And in the end this change availed the Germans little because the development of the Merlin gave such an improved performance to the Spitfire and Mustang that the Focke-Wulf was still outclassed in both speed and rate of climb.

W. C. Devereux, F.R.Ae.S.

I was asked, while the war clouds were gathering in 1939, to prepare a paper for the Association on the subject of ' Industrial Research ' for the Edinburgh meeting. Before that meeting could take place, however, the storm had broken and my paper was never presented. The effort was not wasted, however, since, in reading it through again to-day I am provided with a yardstick against which to measure the progress which our ideas have undergone in these five years of war.

In that paper I made a strong appeal for a very considerable increase in all branches of industrial research as one of the essential factors in maintaining our place in the world, in the face of competition from countries in which research was being carried on on a far larger scale and, even more important, was being applied more rapidly to manufacturing processes and products.

It is very gratifying to me to realise that most of the things I appealed for then are now accepted as essential to our future industrial economy. The realisation of the tremendous tasks which lie ahead of our industry in the post-war years and

of the vital necessity to increase our national wealth at more than twice the rate which it has increased hitherto, has thrown the need for vastly increased industrial efficiency into high relief, for it is upon industry that we must depend in large measure to meet our obligations in respect of Social Security, Full Employment and the many other calls upon our wealth that we have undertaken during these past few years.

There is no longer any necessity for me to call for a greater expenditure and a greater utilisation of the methods of industrial research nor to draw attention to the tremendous efforts that are being made in other countries. These matters have been dealt with many times of late and indeed, it is difficult to find phrases to use in this connection which are not already platitudinous. In all of the multitude of post-war plans which have been published recently there is mention of the need for intensified research activities. The Government has shown its awareness of the problem and the Chancellor of the Exchequer has recently made reference to the subject promising tax-concessions calculated to increase expenditure on the expansion of facilities for research.

As one who has long advocated and practised the application of scientific methods to industrial problems I cannot but be extremely gratified by this rather sudden awakening to the value of industrial research, but at the same time, I cannot help feeling that at least a part of this new enthusiasm is engendered in some by a feeling of desperation arising from the realisation of the difficulties which will confront us after the war.

Those who have experienced the workings of scientific research will know that it is not going to solve all our problems overnight : it takes time and money and then more money to develop a new material or a new process. It calls, above all, for faith and confidence that it will, in the end, produce the goods despite the set-backs which appear from time to time. I hope that this new support from all quarters for industrial research represents a genuine and deep-rooted conviction in its fundamental importance to our national economy and not mere lip service to a new idea, to be cast aside when capital and revenue are in short supply.

I have also noted of late the appearance of the inevitable reaction to this sudden new popularity in which research is now basking. It is being said that some of the foreign research which has been held up to us as a shining example in the past is mere window-dressing. This may be true to some extent, but I do not think this should worry us in the least. I see nothing wrong in window-dressing, in fact, I think that we, as a nation, have sadly neglected this important aspect of foreign trade promotion in recent years. We have been fortunate indeed that despite this neglect consciously to display our wares in the international shop window, this country has continued to produce scientists of world-wide reputation whose work has done much to maintain the international good-will which we enjoyed in the past.

The structure of industrial research in this country is another subject which has been described by numerous authors of late so I need not dwell long on the matter.

As you know, the bulk of industrial research is carried on in the laboratories of industrial firms and to a lesser extent by the Research Associations and Government establishments. A tendency has also been manifest of late for some university research departments to carry out research work for industry. The latter development is one which I suggest should be closely watched, for if it means, as I suspect it may, that the fundamental research work of these universities is being relaxed in order to accommodate applied research, then industry will be the loser for it cannot afford, in the long run, the loss of any of the fundamental research results which it might otherwise expect to be forthcoming.

I believe that our universities might well take stock of the new position created by the demands of industry for fully qualified scientific research workers and engineers particulatly in equipping them for the higher posts in research management and administration. There is undoubtedly a lack at the present time of suitable men for these posts—in some way a scientific education seems to carry with it a false superiority to business matters.

This country has certainly not been backward in its contribution to pure science and fundamental research. It is in the application of the work of our university research workers that we have lagged behind. I think this is due in part to a lack of enterprise on the part of industry and in part to the shortage of properly trained industrial scientists and technicians. We must see to it that the universities turn out a sufficient number of scientists at the same time as they are making these great advances in pure science so as to provide industry with men qualified to interpret this new knowledge. At the same time, industry must play its part by making scientific posts sufficiently attractive to ensure a steady stream of the right type of man through the universities.

The brilliant work in metallurgical physics which is being carried on by Dr. Hume-Rothery at Oxford will have far-reaching effects on industrial metallurgy, but unless the industry can enlist a sufficient number of men with the right kind of qualifications to apply these new theories to practice, then the benefit will go to other countries, particularly to the U.S., where the scale of technological education is on a far larger scale than it is here.

In the light alloy fabricating industry one of the principal research objectives is the development of alloys with improved properties and in particular, the improvement of those properties which influence behaviour under the peculiar conditions encountered by various components under service conditions. This objective calls for the closest possible liasion with the designers and engineers using these materials and for the continuous improvement of the technique and apparatus for testing.

Since the introduction of Duralumin in the early part of the century and the subsequent development of ' Y ' alloy and the R.R. series, a steady rate of improvement has been maintained in the properties of the light alloys but this has

continued along empirical lines largely by the processes of trial and error. The important work of Dr. Hume-Rothery and the increasing data on phase-equilibrium diagrams which is becoming available, already point the way to far greater and more rapid developments in the future.

It must be remembered, however, that theoretical considerations alone cannot govern our progress. Very often they must give place to technological factors. Alloys of very greatly increased strength may be discovered but if may be that they will require specialised treatment in their fabrication, or they may be found subject to stress corrosion and intercrystalline corrosion or for one reason or another their cost may be prohibitive.

Whilst ten years ago, the ' ceiling ' of tensile strength in light alloys was in the region of thirty tons per square inch, gradual development has raised this figure to forty tons per square inch. At the present time I do not visualise any great increase on this figure, and it should be borne in mind, in order to retain a balanced outlook on this question, that, for the majority of uses, the lower strength alloys are likely to predominate in production owing to their greater ease of fabrication.

The field of casting alloys has been characterised in recent years by the conflicting claims of the high strength alloys and the lower strength but more easily cast alloys. Close study and development of foundry methods has now cleared the way for a greater utilisation of the higher strength casting alloys.

The technique of X-ray diffraction is finding valuable practical application in the determination of locked-up internal stresses, particularly in forged components. It has long been realised, of course, that locked-up stresses can limit, to a very low figure, the permissible external stresses which may be applied.

It was clear, that in these circumstances, the performance of engine components could be improved if we could determine accurately the extent of the locked-up stresses. To deal with this we have developed an X-ray Crystallographic method [1] by means of which it is possible to survey a component and to plot the internal stresses present at various points in it. This method of investigating the problem has yielded a great deal of information on the part played by heat-treatment on the distribution of internal stresses and the problem has been resolved into one of establishing suitable methods of heat treatment to give a pre-determined stress distribution in the components.

This ability to study the magnitude and distribution of internal stresses has been of considerable value in the design of components for internal combustion turbines for as a direct result of this work the designers can, with more confidence, use mechanical test figures of the material for design purposes.

Another considerable advance has taken place recently in the study of fatigue. Fatigue failures have long been recognised and have been the subject of very close study for many years but exact information on fatigue limits, particularly under conditions of superimposed tensile and bending or torsion stresses, was not very extensive. Data on fatigue limits at elevated temperatures was very scarce indeed. Improved fatigue testing methods, especially those for operations at elevated temperatures gives the designer, if not the ability to design components directly from fatigue data, at least the means of comparing the fatigue properties of a new material with one of known performance under fatigue conditions.

Improved methods of fatigue testing have undoubtedly played a very important part in the rapid development of the jet engine. However, this new field is so very wide and the problems so numerous that the new-born science of laboratory component testing using ' stress-cost ' and electric strain gauge method and the stressing of components to simulate operating conditions is likely to be an increasingly important factor in increasing the rate of turbine development.

I could not help thinking while listening to Dr. Hooker's account of the development of the Rolls Royce Merlin Engine, although he did not mention this particular aspect, of the enormous amount of single cylinder testing which goes into the development of an engine. I think it would be safe to say that a very large proportion of single cylinder testing time is wasted because of our lack of knowledge of the materials used.

In my opinion one of the most urgent tasks to be undertaken by the material research laboratories is the development of techniques and machines for testing methods to simulate far more closely the actual conditions under which the materials have to perform in service, and which will enable him to supply the engineer with more comprehensive and reliable data on the performance of materials in respect of temperature, abrasion, internal stresses and so on. Only by doing this will the material supplier be able to ' cash-in ' on his research more quickly and avoid the five or ten years' interval between development and application to which Dr. Sykes has referred.

A great deal of interest has been shown recently in a new approach to the study of materials under vibrating conditions using the property known as Damping ; the property of materials which controls the amplitude of vibration at resonant frequency owing to the absorption of energy by the material itself. It was thought at one time that this factor was of importance in structures, but measurements of the actual damping of alloys show that, at low amplitudes, this is so small as to be insignificant as compared with the damping which occurs at the joints in the structures.

The measurement of damping by various methods had produced widely different results and has given rise to some controversy. Careful measurements show, however, that while the actual damping capacity is a characteristic of the material and is independent of amplitude, it is found that this is so only under conditions involving low or vanishing amplitude and is certainly confined to the range in which the metal is truly elastic. As soon as the amplitude of vibration becomes large enough to produce plastic deformation the apparent damping increases markedly. Measurements on light alloys show that the increase in damping coincides with

[1] Frommer and Lloyd, *J. Inst. Met.* 70 (3), 91–124.

the beginning of plastic deformation. Moreover, the damping value often increases with the number of reversals.

Such observations indicate a relationship between the damping values and fatigue and if the experiments which we have in hand prove as fruitful as they are promising, it may soon be possible to establish the fatigue properties of a material at normal and elevated temperatures very much more quickly than is possible at the present time.

In addition to the kind of laboratory research work usually referred to as industrial research, I think we must also include in this term the newly emerging technique of applied economic research and market research. Some in my audience may have seen the Plan for the Industrial Reconstruction of West Cumberland which I completed earlier this year. For the benefit of those who have not yet seen this plan, I would say that it is an attempt to assess as thoroughly as possible the natural resources of the area and the future demands for products based on those resources and, upon the basis of this survey, to recommend the introduction of new industries to manufacture these products and to suggest expansion or contraction of existing industries. By such means it has been possible to produce a plan soundly based on the natural resources and amenities of what was formerly a Depressed Area, which will give full employment of a more varied and thus of a less vulnerable character than hitherto and which, at the same time, will raise the average standard of living of those working in the area.

I would like to see a great expansion of this sort of investigation which, although carried on mainly in the office and in the field is, I believe, an important part of applied research for industry.

Market research is rapidly assuming an important function in industry, especially in relation to other forms of industrial research and development. I think that in the past, we in this country have failed, on numerous occasions, fully to exploit the results of our own scientific research work because we have failed to realise the far-reaching effects of new inventions or, realising them, have not had the courage to lay out the capital necessary to achieve a sufficiently large output to meet the demand, thus allowing others to get into the market on the ground floor.

The point at which research ends and development begins is not always an easy one to define, in fact, it is usually desirable for them to overlap to some extent so that development may commence even before research is finally completed.

The importance of a proper approach to the problem of the development of a laboratory process into a manufacturing routine cannot be too strongly emphasised. I am afraid that in the past this important link has been omitted in many industrial organisations and it is still not exceptional for a new process to be passed directly from the laboratory to the works with an inevitable interruption of the smooth flow of production and usually an unnecessarily long delay in getting the new process to work on a production scale. This also has undesirable repercussions on the research laboratories, for the temptation is strong to do development work there so that the process may succeed when handed over to the works. This results in a diversion of the research efforts.

In my own organisation we have found it desirable to maintain several development departments each dealing with a particular aspect of our work. For instance, there is the Process Development Department which deals with the development of new processes and improvements in old processes which come within the scope of our normal day to day manufacturing activities, i.e. the casting, working and heat-treatment of alloys. Then we have the Engineering Development Department which carried on the development of new ideas for the engineering uses of the materials and goods we manufacture. This work is directed to the improvement of processes which are performed on our semi-manufactured products after they have been despatched from our works. It may be regarded as a development service on behalf of our customers but in reality it is very much more than that, for we have found that, unless we can provide this kind of information on the use of new materials, their full utilisation is delayed for a very long time, perhaps even for years while the users gradually change over from old materials trying out one part in the new materials at a time.

It has been my experience as a supplier of structural materials that it is not enough merely to develop a material showing greatly improved mechanical properties. We have to go very much further than this. We have to supply a great deal of design data for the use of this material. If we do not do this it will take five or more years before sufficient practical experience to be built up gradually for the properties of the material to be exploited fully.

I would like to make one final observation on applied research in other directions. It arises out of Prof. Blackett's remark yesterday that the research worker should apply himself less to the 'frills' and more to the task of producing goods more cheaply and in larger quantities. I rather fancy that this observation was aimed at the fundamental research workers in industry. I do not think he means that quality should be left entirely alone, but I do agree that it is very desirable that, when a laboratory has developed something worth while, arrangements should be made to get it into production quickly without necessarily waiting for final scientific perfection.

I am very conscious of the shortcomings of our metallurgical industries in respect of the other point he raised—namely, the question of prices. The high prices charged for the products of the basic industries undoubtedly place our manufacturing industries under a considerable disadvantage. I am frequently shocked, when I look at our die costs to see how much we have to pay for steel compared with prices charged in other countries. My mind is not made easier when I realise that in these other countries, wages in the iron and steel industries are twice as high as they are here.

In the United States the pit-head price of coal is ten shillings a ton less than it is here. We are not tackling these problems in a big enough way. They are so very serious that we cannot afford

to seek the cure in the empirical way in which we are now attempting to deal with them. We must start off with research into all of the many aspects of the problem. We much investigate thoroughly the conditions which have produced this grave situation. We must make a careful study of industrial relations and industrial psychology. Only after intense research into all aspects of the problem can we hope to find the proper solution.

I am intensely annoyed when I put a piece of coal on the fire and my wife says 'Remember what Major Lloyd George said.' I always feel that that is not the way to tackle the problem.

In the time at my disposal I have been able to deal only with a few of the more general aspects of industrial research and development. That these matters are of supreme importance and that our total research effort must be rapidly increased, no one will deny. Much remains to be done to encourage all branches of our industry to increase their research effort. The supply of men trained for industrial research and development work must be increased without delay, and above all, we must not allow the technique of the rapid application of new scientific knowledge which we have learned under the urgency of war to fall into disuse.

Only by the fullest and most rapid application of research in the sciences, in engineering, and in economics to our industries can we surmount the great difficulties which will confront us in the post-war world.

J. C. Swallow

Plastics

In this talk I shall confine myself to synthetic organic thermoplastics. The increase in the variety and output of these products has been one of the more spectacular developments of the chemical industry during the last ten years, and there is every indication that the production of further novel products will continue. It has been and continues to be stimulated to a large extent by the demand by other industries for new products with better properties, and by the increasing ability of the chemical industry to fulfil these needs by large-scale manufacturing processes. Early research effort was directed towards products resembling natural materials—as in the case of synthetic rubber—but this has now given way to the synthesis of plastics with combinations of properties for specific purposes.

Thermoplastics can be rigid or flexible, rubbery or leathery, tough or brittle, transparent or opaque, but they all owe their properties to the fact that they are polymers. That is, they are composed of macro-molecules, or, as they are more frequently called, chain molecules with primary valency forces as links, whilst the chains themselves are held together by weaker secondary forces; and Nature provides polymers in abundance in cellulose, rubber and proteins. The particular properties of a plastic will depend on the chemical units which make up the chains, the length of such chains, and their arrangement in the solid state. Such chains are built up synthetically in two ways, by polycondensation and polymerisation. In polycondensation, molecules capable of combining with the elimination of water can be made to condense to give long chains, as in the case of nylon, whereas in polymerisation, molecules containing double bonds, when brought into the correct chemical environment, link up and form long chains. As a result of scientific advances we now know that synthetic polymers are polymolecular, that is, that owing to the chemical processes by which they are made, chains of varying lengths are inevitably produced, and therefore we can have a wide range of macro-molecules having different distributions of lengths about a given average. This average chain length can be varied by conditions of manufacture, and to a certain extent the distribution about a given average also, and many of the mechanical properties are greatly affected by each of these two variables. The chains can execute a whole variety of molecular movements depending on temperature, and they can curl and uncurl, and if this latter process can take place quickly, rubber-like elasticity will result, whereas in plastics these processes are hindered and take place slowly. If the chains have suitable symmetry they may be able to pack together along sections of their length in a regular or crystalline manner, whereas if little or no state of order is possible, an amorphous structure results. A few examples from the better known plastics may serve to show the variation of physical properties resulting from such structural features; thus, polymethyl methacrylate is amorphous and transparent; polyvinyl chloride, also largely amorphous, is a rigid rather brittle material. The properties, however, can be varied in the direction of greater flexibility by the introduction of organic compounds known as plasticisers, the precise action of which is not yet properly understood, but which confer greater flexibility on the product.

In the case of nylon, however, the chains are held together by very strong forces, and further these chains can pack together closely and crystallise over part of their length, and by giving the crystallites containing the chains further orientation or order by stretching it in thin sections, we are able to make strong fibres or filaments. It is necessary to take the temperature to 264° C. before the crystalline arrangement is broken, when the polymer becomes a liquid of low viscosity.

Again, in the case of polythene, we have a plastic with the simple crystalline structure of a paraffin hydrocarbon; here, however, the forces between the chains are weaker and the crystalline arrangement is completely destroyed at a lower temperature of 115° C.

Polyisobutylene, another hydrocarbon polymer, is composed of molecules which pack less well together, and this leads to a weak rubber-like structure. When it is stretched, however, the chains become aligned and crystallise in the same way as natural rubber.

By suitable choice of reacting chemicals in the condensation or polymerisation reactions, a cross-linked structure can be produced, in which the chains are joined to each other by primary valency bonds leading to a more rigid and brittle structure, but not necessarily one of greater strength. Further, the chains may be partially broken down or shortened by heat or oxidation, or again they may be treated chemically so that new chemical

groups or atoms are introduced into the chains by chemical substitution. Also, by introducing second or even third components into condensation or polymerisation reactions, mixed chains can be made with consequent modification of properties.

Some new plastics have resulted from accidental discoveries and some from deliberate syntheses directed towards desired ends. Our increasing knowledge of the laws relating structure and properties together is making it possible for us now to design, within limits, large molecules or classes of large molecules for specific purposes, a notable example being plastics for the electrical industry; but our knowledge is still incomplete, and we are not yet able to build molecules to specification as regards mechanical properties.

What is involved industrially, then, in making a new plastic and bringing it to the stage of industrial use? As in the case of the development of any new chemical, the first step to industrial production will normally be a pilot or semi-technical plant in which design data is obtained for the construction of larger scale plants, but it is important also as a means—at the same time—of producing sufficient of the new plastic for purposes where hundredweights rather than pounds are required. The making of plastics on the large scale, however, does present certain special problems in the chemical industry. High yields and low costs are of no use unless the properties of the product are reproducible, that is unless it has the correct molecular weight and distribution. Polymerisation processes are generally highly exothermic, and in order to remove the heat in a controlled manner it is desirable wherever possible to use continuous processes. To accomplish this may mean a very high standard of control involving specially designed instruments. Again, successful production calls for a high standard of purity of the raw materials. Impurities may remain in the final product, leading to the deterioration of the mechanical and electrical properties, or they may cause the chains to terminate prematurely, leading to a product with variable properties. An apparently cheap source may prove expensive by the time it is brought into the state of purity required for the successful synthesis of a plastic. Lack of reproducibility can hinder an industrial development to an alarming extent.

The organic and the physical chemist, the physicist and the chemical engineer have their vital parts to play in this stage of the development, but experience shows that for success all their efforts must be combined with those of the engineer, both in producing and using the plastic, for without him their experimental findings accumulate behind inadequate facilities for their exploitation. Ideally, in a development of this kind, we should have organic and physical chemists, physicists and engineers, working as a team up to the point where large-scale plant embodying the results of the pilot plant has been designed and operated.

Assuming that conditions of production have been established to give a product with reproducible properties, the problem arises of fabricating it into wrought forms and using it. This part of the development will go more quickly if we possess as much knowledge as possible of the properties of the polymer in the solid state, which can be provided by the tools available to the physical chemist and the physicist for the examination of the polymer. To mention only two of the most recent ones: X-ray spectroscopic measurement has now been established and is invaluable for the examination of the crystalline plastics already mentioned, the structure of which renders them amenable to such analysis, whilst infra-red analysis is of increasing importance in the analysis of fine structural features. In addition to such work, which may be done in the university or in the industrial laboratory, or in both, there is the additional problem of the measurement of the mechanical and electrical properties of plastics, and the effect of temperature on these properties. Most plastics, on account of their structure, have mechanical properties which are time-dependent, arising from the rate of movement of the long chains which compose them. Thus, a plastic which is flexible at low rates of strain may become brittle at high rates. There is little doubt that the development of fundamental principles of plastic flow, and the perfection of methods of measurement, will lead to plastics being used more widely because such information will give the engineer a more accurate picture of their behaviour in practice over long periods of time, and it will also probably lead to improvements in synthesis. Lack of such exact knowledge does not, of course, prevent the extensive use of plastics at the present time, because in every industrial development there is art as well as science.

Coming now to the use of plastics in the forms required in industry, it is obviously necessary to be able to fabricate them into desirable wrought forms as in the case of metals, such as rod, sheet, tube, tape or film, and to devise processes for cementing, welding, machining, moulding, extrusion, rolling and mixing. The problems involved here are just as great as those met with in the fabricating of, say, new metal alloys, and the more knowledge one has of the basic properties of the plastic, the more likely is it that elegant and efficient techniques for these operations will be evolved. The orientation effect mentioned earlier, that is the lining up of the molecules or groups of molecules by the application of mechanical stress, leads to different mechanical properties in different directions, and this is of great importance in technical processes. The gap has to be bridged between the knowledge of the physicist, the chemist and the engineer, at this stage of the development. This point cannot be over-emphasised, since the tendency at the present time is towards the production of plastics which require new techniques in handling them. Plastics which will process easily on orthodox machinery may not, for that very reason, have the desirable high temperature properties demanded to an ever-increasing extent by the electrical industry in the field of high voltages and frequencies.

A study of the properties of any polymer will generally indicate some, at any rate, of the industrial uses to which it may be put, and this will lead the team working on the methods of fabrication of the polymer to propose the production of specimen articles or prototypes. Such prototypes may be a cable, a complicated moulding, a lighting fitting or a package. It is important that at this

stage of development there should be a willingness to make prototypes for trial because it is from such trials that new effects are discovered which are often impossible to observe on a small scale, and which in turn suggest new research targets.

The trend of modern plastics development appears at the moment to be towards a greater variety of products, many of which are used in combination to obtain desired technical effects, and it will be appreciated that with such tremendous possibilities of synthesis in polymeric chemistry, it is most necessary in industrial development to have available as many clarifying principles as science can provide, relating properties to structure, in order to be able to select and concentrate on the development of those plastics which are likely to be most useful, and to prevent dissipation of research effort. Scientific advances in the university or in the industrial laboratory are at the best of limited value in this industry, unless technological effort, that is the development of industrial processes for the manufacture and fabrication of the plastic, is made on a comparable scale. One activity is not a substitute for the other.

A. L. Bacharach
The Industrial Manufacture of Vitamins

To apply the term 'synthetic' to the vitamin industry is both inaccurate and misleading. First, on the industrial scale one of the vitamins is always, and another frequently, prepared by concentration from a natural source. In the manufacture of others, molecular changes are brought about in molecule without any synthesis, *sensu stricto*, being accomplished. In the second place, it is most undesirable to adopt any description that tends to perpetuate a belief in the difference between a 'synthetic' and a 'natural' vitamin (provided each of them is a pure chemical substance). They are either chemically identical, or they are not, but this has nothing to do with their origins or modes of preparation.

Large-scale manufacture of vitamins is a new branch of the chemical industry. The first vitamin concentrate for medicinal use was made in this country about twenty years ago; it was an extract prepared from cod-liver oil, following an American patent taken out by a bio-chemist at a New York university and developed industrially in the U.S.A. and here at almost the same time. It was a preparation of vitamin D, standardised biologically. Very soon after it was first made available, it was being successfully used all over the world for the prevention and cure of infantile rickets.

The process used is typical of, though not identical with, the method still in practice for making concentrates of vitamin A from fish-liver oils and of vitamin E from certain vegetable oils, such as wheat germ, cotton-seed and linseed. Most of the vitamin E used medicinally, however, is to-day made synthetically from coal-tar derivatives. The preparation of vitamin A and vitamin E from natural sources is accomplished either by saponification and extraction or by 'molecular distillation,' the generally adopted name for what is in fact a method of volatilisation at very low pressure.

The manufacture of vitamin A concentrates by saponification and extraction represents the largest operation carried out in the field of vitamin manufacture. For the enrichment of margarine in this country during the war, which requires that 500 units of vitamin A be added per ounce, it can be calculated that six tons of a concentrate containing one-third its weight of pure vitamin A is required per annum, on the assumption that every individual in the country uses six ounces per week of enriched margarine. If it is assumed that these concentrates are made, on the average, from fish-liver oil having a vitamin A content of 20,000 International Units per gram, then it can be calculated that this involves, assuming no loss during manufacture, a yearly input of 3,000 tons of oil.

The manufacture of vitamin D by the irradiation of ergosterol with subsequent chemical separation of crystalline calciferol is also carried out on a large scale, but the quantities involved are much smaller because of the extremely high potency of vitamin D. Thus, for enriching margarine at a level of 60 International Units per ounce, and allowing six ounces per head of the population, it can be calculated that approximately 20 kilograms of calciferol are required per annum. The process, however, assumes much larger proportions if one remembers that this ergosterol has to be prepared from about one ton of specially grown yeast each week.

Besides their use in the enrichment of margarine, vitamin A and vitamin D are both employed medicinally, especially the latter for the prevention and cure of rickets. Vitamin A has been found effective in treating certain forms of night blindness and poor dark-adaptation, but it is used more prophylactically than therapeutically.

The use of vitamin E in medicine, veterinary as well as human, is not very extensively practised, chiefly because the experimental evidence for its value is not known to, or has not been accepted by, practitioners. Nevertheless, there is a continued demand for small quantities, particularly in the United States, where its use in the treatment of habitual abortion in women, and to prevent miscarriages, continues on a partly experimental basis. Synthetic tocopherol, the name given to all three of the known isomeric forms of vitamin E, is prepared from a toluene derivative and from phytol, which has itself to be made by the degradation of chlorophyll. Thus, synthetic tocopherol is only so called by a half-truth, for there is no commercially practicable synthesis of phytol.

A form of vitamin D having considerable industrial interest and growing importance is vitamin D_3, which is prepared by irradiation not of ergosterol but of 7-dehydrocholesterol, a chemical conversion product of pure cholesterol. Although calciferol (sometimes also called vitamin D_2) is as effective in the treatment of human rickets as cod-liver oil, and the same is true of its action on experimental rickets in rats, chickens show a very marked discrimination between the two compounds, and are relatively unaffected by calciferol. Vitamin D_3 is almost certainly identical with the vitamin D present in cod-, halibut-, tuna- and other fish-liver oils. Its commercial production in this country runs into

many thousands of millions of units per annum, and has rendered the admittedly much reduced poultry industry virtually independent of supplies of fish-liver oil, much of which was of Japanese origin.

An interesting example of man's improvement on nature is to be found in the position of vitamin K. Two forms of this are known; one is found in green leaves and the other in certain animal products, such as rotting fish meal, though it is probably of bacterial origin. Both compounds are substituted methylnaphthoquinones with side chains rendering them markedly fat-soluble. For therapeutic purposes, the simple methylnaphthoquinone itself, officially known in this country as menaphthone, is found to have advantages over the naturally occurring vitamins, which are no longer used in practice. Menaphthone and simple derivatives of it are having a rapidly extended use not only in the pre-operative treatment of obstructive jaundice, but also as a prophylactic measure against hæmorrhage of the new-born, for which purpose it may be administered to the infant immediately after or to the mother a few hours before, delivery. In its absence, blood loses its clotting power, owing to a lowered prothrombin content, and in certain circumstances fatal hæmorrhage may follow.

Among the water-soluble vitamins, ascorbic acid (vitamin C) is pre-eminent in large scale manufacture. No figures are available in this country, but it is believed that the United States produces and consumes about 100 tons per annum. Whether or not the conversion of glucose, a sugar with a 6 carbon chain, through sorbitol and sorbose to ascorbic acid, in which the same 6 carbon chain is present, is rightly to be called a synthesis, is a matter of definition, which need hardly worry us, once we have agreed to discard the term altogether.

Apart from its use for the cure and prevention of scurvy under medical direction, ascorbic acid is consumed in considerable quantities by the general public. It is harmless, excess has never been known to damage any human or other animal, it is relatively cheap, it has a slightly acid and not unpleasant taste, and seems to have taken the public fancy. Industrially it has little use at present, but it seems likely that some quantities will be required after the war for the addition to jams and other preserves, which could then be sold with a claimed standardised vitamin C content.

If vitamin B_1 is not manufactured on the same scale as vitamin C, this is mainly because the human requirements by weight of the latter are much greater than are those of the former. Nutritionists' estimates vary, but the daily requirement of ascorbic acid is held to be between 25 and 75 milligrams, whereas that of vitamin B_1 (aneurine or thiamine) is considered to be from 1 to 3 milligrams. Thus it follows that even the large amounts required for the enrichment of bread do not bring the manufacture of vitamin B_1 on to the scale of the heavy chemical industry or, indeed, to that of many fine chemical operations. Had the policy of enriching white flour with vitamin B_1 been followed in this country, instead of that of lengthening the extraction of flour, it had been decided to add 200 milligrams of pure vitamin B_1 to each sack of flour. Assuming that seven ounces per day is the average consumption in this country of flour used as bread per head of the population, this would have necessitated the production of five tons of the pure vitamin per annum. The chemical processes involved are difficult and many, the precise number being naturally determined by the stage at which the synthesis is considered to begin. Here, for the first time, we have a genuine vitamin synthesis, in the sense used by the most pedantic organic chemist, for every one of the compounds used at the final stages has been built up from simpler molecules.

In the United States enrichment of bread has been carried out extensively. A very considerable proportion of the nation's bread contains not only added vitamin B_1, but also added nicotinic acid and added riboflavin. The former is probably made by the degradative break down of crude nicotine; in the United States it has been found that the chemical knowledge of the general medical profession is such as to make it desirable to call this vitamin niacin, as otherwise the practitioner might be afraid to use it, in the belief that it possesses the poisonous properties of nicotine itself! Riboflavin is built up from coal-tar derivatives by an elaborate and difficult synthesis, and the fact that the vitamin is now commercially available in the United States at sufficiently low a price for its incorporation into enriched bread, without any increase in the price of the loaf, is a high tribute to the skill of American chemists and chemical engineers, which is not less than that of those who, in this country, had previously elaborated the preparation of pure calciferol from irradiated ergosterol or the manufacture of ascorbic acid from glucose. According to Kent-Jones (private communication) figures reaching this country indicate that the voluntary demand for enriched white flour reached 65 per cent. of the total flour consumption, and the cost of the enrichment has been estimated at 9*d.* per annum per head of the population; many American physicians attribute certain observed improvements in public health to the enrichment of bread with these vitamins.

Other vitamins that have been synthesised, but not yet manufactured on a commercial scale, include certain fairly recently characterised members of the 'vitamin B_2 complex,' such as pantothenic acid, pyridoxine (vitamin B_6) and biotin. Should the demand for these become sufficiently large, either for a relatively high-priced product to be used medicinally, or for a relatively low-priced product to be used industrially, there is little doubt that supplies would become available as they have done in answer to the demand for those vitamins that are at present manufactured by the chemical industries of this and other countries.

THE FUTURE: WHAT SCIENCE MIGHT ACCOMPLISH

SATURDAY, JANUARY 13: AFTERNOON SESSION

ADDRESS BY THE RT. HON. LORD WOOLTON, C.H., CHAIRMAN OF THE SESSION, ON LESSONS FOR PEACE FROM WARTIME TRIUMPHS

THE British people are persistent and unrepentant opportunists. An unreasoning faith in our destiny has successfully sustained us throughout the centuries, and in the end that faith has always been justified. When victory has finally been won it has been so welcome that we have rarely followed it by inquests; it has not been our national habit to let the future profit from the lessons to be learnt from the failures of the past.

We have been content to be unprepared for the dangers of the future and we have trusted to our natural capacity to meet the circumstances of the time when they arose. There are indeed many experienced students of politics who regard this as a sound political policy: they claim that the future is hidden so completely in the unknown that undue preparation is wasteful and likely to be futile. On the other hand there has developed in recent years a new school of political theory which places deliberation and thought above instinct and the popular judgments of the time: a school which believes in the submission of the people in general to the Government of selected groups, and organises the whole of the society under its control to achieve predetermined ends: a society that is rarely caught unprepared, and, as recent history has proved, can attack great national projects with thoroughness and competence, fortified by the capacity of its ablest brains.

Such a philosophy abandons freedom in order to secure the benefits of specialised planning.

This is not the British way. Our instinct is to look with suspicion on those who would plan our future ways of life. But equally surely we shall be wrong if we fail to take deliberate action to see that we have all the knowledge of facts, and the power which knowledge gives us over the forces, whether human or material, which constitute the make-up of our social life. I reject, therefore, the political approach of the totalitarians, in spite of their efficiency. But I reject equally and emphatically the laissez faire doctrine of trusting to chance that we shall be all right on the night.

Public opinion will determine this issue, and I believe it will demand that in certain spheres the Government should exercise a greater measure of influence than it did before the war. So long as Government keeps in step with public opinion in this matter we need have no fear of totalitarianism, the bogy of bureaucratic rule or of loss of freedom and liberties which we so rightly prize.

No one who has been in Government during these last five years can be blind to the fact that the national policy during this current century brought us very near to defeat, and did not make use of the knowledge that was at our call. We were living at a time when the men of science were making great discoveries over the wide fields of knowledge. We gave them little support in their academic pursuits and small encouragement in the wider application of their knowledge. The universities were almost divorced from the practical men of affairs, and deliberate planning to meet either the needs or the dangers of the future met with no encouragement.

Wars wake people up. Those who take part in them gain vast new experiences that widen the horizons of their minds and increase their knowledge of men and of countries. Those who remain at home and in anxiety reflect on the mistakes of the past, and hope that the future will be better than the past.

This is the mood of the time: it was the mood after the last war. The hopes of 25 years ago were born to disappointment. Need the hopes of to-day prove equally barren? I think not: it was this belief that led me to accept the office of Minister of Reconstruction. I believe that if we garner the experience the nation has gained and endured we can secure great benefits for the future, and above all if we use the knowledge which the intensity of necessity in war has given us, we have much material on which to reconstruct a healthier and a happier society in the future.

Let us look at this knowledge we have gained and see what we can do with it. That is the scientific approach to politics. You will understand my inclination to take my first examples from food about which I can speak with personal experience. Would I be unjust if I said that before the war the major practical application of science to food was in its commercial sphere? Processes for preserving it against putrefaction; for making

it more appetising ; for producing substitutes ? I do not decry these aspects in so far as they helped to improve our standard of life, as some of them certainly did. Food was regarded largely as a matter of appetite. And yet what is food ? It is the primary essential to all human growth. We thought we had it in abundance, and yet not less than 25 per cent. of the people were suffering from malnutrition on the one hand and improper feeding on the other.

Remember that this happened after all the experience of the last war and the grave disquiet aroused by the discovery that so many of our young people were of the C3 category of military fitness. We remained unprepared either to breed a nation that would be physically fit or to take the precautions to grow and to store enough food to insure us against the growing dangers of submarine attack, which were well known to our naval scientists. Within a few weeks of my taking office in April 1940, we were faced with a drop in our food imports of 50 per cent. We were saved from starvation by the application of scientific knowledge to the problem of securing the right foods, not to satisfy our appetites—you probably observed that—but to give us nutrition. This approach met with the approval and support of the public : it commended itself as a factual approach based on knowledge. With the aid of this science it was possible to lay down and carry out a national policy which aimed at distributing food on the basis of its nutritional value, so that the vulnerable classes—mothers, expectant women, infants and children—should have full protection because their needs were special, and the rest of the population should have a physiologically adequate diet.

The British Association may take credit for what it did to prepare the public mind for this approach. Year after year, beginning with the Presidency of the father of the science of nutrition, Sir Gowland Hopkins, at Leicester in 1933, and followed by the discussions on the social implications of nutrition in 1934 at Aberdeen and the great debate on its relation to agriculture and human needs at Norwich in 1935, the British Association annually hammered home the facts. People were made to realise that nutrition, far from being a fad, was simply the plainest of common sense.

Thus the Ministry of Food embarked on a policy the public understand, and they accepted it when it applied to the problems of the nation's food the knowledge and standards which science had made available. Let me repeat. It not only encouraged science. It applied it, to the advantage of the whole nation. It made direct use of the scientist ; it profited from advances which scientific research had made in the handling of food, such as dehydration, which had a double value in that it saved shipping space as well as preserving food.

At the same time scientific research applied to agriculture was making it possible for Britain's farmers to increase the yield of the land beyond the most hopeful public expectations. Now, in the sixth winter of the war, the great ' combined operation ' which the Food Front represents, and in which the scientist has played such a conspicious part, finds our standards of health well maintained, and in many ways actually improved, in spite of the stresses and hazards of war, and it finds British agriculture becoming a mechanised science and serving a great national purpose.

I do not merely hope, but say it is essential, that the measures taken in this war in the stress of emergency and with such beneficial results should be carried on in the days of peace. The steps taken to increase the consumption of milk, to encourage the eating of selected vegetables, to provide certain classes with orange juice, cod-liver oil, vitamins and calcium tablets, to develop communal feeding and meals in factories, and to expand the meals-in-schools scheme—these are not steps along the blind alley of opportunism enforced by war ; they are and must remain an ordered march of progress along the open highway to the health of the future nation.

But it is not only in terms of feeding and of health that the scientist has rendered conspicuous service to the nation at war. From the first this has been a scientific war. In the earlier stages science, used defensively, helped to stave off defeat ; now, in the offensive phase, it is making victory possible for the Allies. War acts as a forced draught upon inventive genius, and it is not without pride that we can claim that British research workers have maintained their great reputation for ingenuity and enterprise and knowledge. Some thrilling chapters of the story of the success of science in arms have been given you by the authors themselves at this conference. They will be amplified when the censor is able to relax his vigilance and disclose the romance that lies behind. What I can do is to point the lesson for the future which is provided by these brilliant achievements.

Even more significant to the theme I am developing, has been the application of the scientific method to the operational field. Eminent scientists are found at the right hand of our military, naval and air strategists, applying to combat the same scientific methods which they use in their peacetime research. Taken out of their laboratories,

away from the theoretical problems of physics, chemistry and biology, they have been at work on problems of civil defence, of combined operations, of defeating the U-boats and even of operations on the battle-field. These men of peace, working in an unaccustomed field, have given us great hopes of what planned operations may achieve in other fields of labour.

In the early hours of June 6, D-Day, no one knew what was to be the outcome of the fateful crossing of the Channel. And no one knows to-day what will be the outcome of the great experiment in reconstruction on which we are to be launched when the war is over. One thing, however, is sure. The part the scientist can play in the operations that lie ahead of us in peace will be as great as the rôle he has performed in the military operations which have taken and are still taking place. But the scientist must be given his chance to serve the country. We shall look to the scientists to make their contribution, not only by their researches and by their ingenuity in evolving new materials and new techniques, but by their application of the scientific method to our social and industrial problems as they have done to large-scale operations of war. Housing, food, health, trade and industry, and the effective use of manpower are all subjects full of opportunity for the contributions of science to new knowledge. We cannot afford to lose what we have gained amidst the disasters of war.

On the food front our wartime experience of feeding and nutrition has provided us with many practical examples of what must survive in the post-war world. We have acquired an understanding of the social importance of food and its scientific use. We know now what we need to rear a nation, strong at birth and using food to develop vigour and maintain health. It we so use it in peace we shall save not only human suffering but millions of pounds a year that have previously been wasted, from a national income point of view, in physical ill-heath and consequent industrial incompetence. In the post-war years we shall be too poor to be able to afford the extravagance of preventible ill-health.

Scientific knowledge to ensure positive health must be extended and spread throughout the land, among all classes and the young and the old. I hope this Association will continue its work of education. Do not allow us to return to starchy satisfaction and forget that food is the fuel of human health. I want to see in the curriculum of every school a short and compulsory course of instruction on this subject, and I should like to think of the doctors of this country taking a more active part than they have done in teaching the laws of health through the laws of nutrition. That is work which must begin with the teachers in the medical schools.

Now what about housing? That is the problem which most interests the public at the present time, now that they are no longer in danger of starvation. I am in full agreement with those who are demanding that post-war reconstruction must begin with housing. All I ask is that, in so far as the house-builders are now in the Armed Forces, they shall finish off the enemy abroad before they tackle the enemy of bad and inadequate housing at home. The problems of the scientist on housing are twofold. Firstly, to determine the standard of housing that will enable people to live healthy lives. I think you have done that. The next problem is to apply scientific knowledge to the design and construction of houses: to use scientific method to build houses at less cost. Science must come into the home as well as into the kitchen. Ventilation without draughts: windows that keep out the cold but let in the vital rays of the sun: fire grates that give the cheerfulness of a good coal fire to a room, but use the heat that goes up the flue to warm the rooms on an upper floor—and fires that do not destroy the amenities of the neighbourhood by a dreadful pall of disfiguring smoke. There is a problem for the applied scientist—to combine efficiency and cheerfulness in the domestic grate. I am much impressed by the scientific work that has been done on building research, and I believe that when we get the men back from the war we shall, as a result of wartime planning, make a contribution within three years to the housing problems of this country such as we have never seen in any previous decade. Not only will houses be built, but they will be homes in which the scientist will have helped both to eliminate much unnecessary drugery for the housewife and to improve the health of the people who live in them.

In terms of health, the nation's fitness has been maintained in wartime with a gratifying and almost unbelievable success and valuable lessons have been learned for the future. The fighting Services, with their millions of men and women under controlled conditions, have provided a wealth of experience of social medicine which so rightly has been developed for our warriors, but must be translated into peacetime civil practice. There have been great advances in research —in therapeutics, surgery, the rehabilitation of the injured, maternity and child welfare, and in psychology and psychiatry. The mass infections, which in past wars have accounted for more casualties than the

fighting itself, have been fortunately conspicuously absent in this war. Even in the impossible conditions of the jungle, which defy description and almost defy the imagination, doctors have accomplished wonders. The research work on penicillin which has, with Government help, been done in this war would have taken very many years in times of peace. Yet human life is as valuable in peace as it is in war.

The scientific achievements of war are a challenge to everything we can do in times of peace. In the future the advances in medical and surgical science must be made available to everyone, not only when they become cases for the doctor, the dentist or the hospital, but in preventing them from becoming such cases. A national health scheme, which as a Government we have put before the country is a part of the social reform programme of the Government's reconstruction plans. Costly though it will be, it will pay its way.

The importance to the success of this programme of an expansion of trade and industry cannot be over-emphasised. Here the scientist must figure as prominently in the peacetime factories as he has done in the war industry of this country. We must mobilise and utilise scientific research in ever-increasing measure if British industry is to recover and retain a pre-eminent position in world markets. We cannot rest on our past. Our reputation for quality must be preserved, but we must see to it that we take a lead in technical advances. Our peacetime products must embody that scientific ingenuity of which the world has been given plenty of evidence of our capacity during the past five years. The skill of our craftsmen must go hand in hand with the efficiency of industrial methods. Moreover, our goods will be judged by their appearance as much as by their quality ; more attention must be paid to design in industry. In short, we must marry art to technology ; designers must be trained not only in the principles of their art but in the technical processes of industry.

The field of fuel technology affords an example of the scope of the research worker for benefiting the nation as a whole as well as a particular industry. The possibilities of research into the development of a better use of coal are enormous. In 1913 only 15 per cent of the available energy in every ton of coal was tapped. By 1938 this percentage had been doubled. It has been estimated that, if this 30 per cent. could be increased to 45 per cent., it would be worth £60,000,000 a year. Sixty million pounds a year, for an expenditure on research of—shall I say—£1,000,000 ! What a dividend for a commercial man to get ! Does research pay ? I need hardly point the moral.

For trade and industry as a whole an expansionist policy has been outlined by the Government, who have for the first time accepted a full share of responsibility for maintaining a high and stable level of employment. If we are to succeed with this programme, it must be our concern to see that new industries, which modern science has made possible, are encouraged and developed in this country. In the twentieth century we must not repeat the story of Perkin's discovery of the aniline dyes thrown to the German dye-stuff industry for exploitation. In the future peace, as in the war, we shall need to borrow heavily on the resources of science. For the best use to be made of these resources a number of conditions must be observed and fulfilled. In the first place there must be a closer contact between scientists in industry and those in universities, between the theoretical and the practical, the pure and the applied. There must be more integration between research and development. Lastly, there must be more pooling of information about new developments. War has forced us to adopt the principle of the ' common fund.' Scientific knowledge must be common knowledge. And those who possess it must place it above personal or sectional interest, and show that this principle can exist and thrive when the danger from the enemy is no longer a driving force.

Research costs money. The State and industry must see that this money is forthcoming. It must not be possible in the future to say that only one-tenth of one per cent. of our national income is spent on science. Scientific research must not be left to live, as it has been in the past, from hand to mouth. Research must be well and securely endowed, and the results of research must not be left like foundlings to the tender mercies of the casual commercial passer-by.

In war we have seen the value of endowing development, of nursing new ideas and techniques through the difficult period of infancy and teething troubles. Someone must take care of the infant idea : it may be an invaluable national asset. You will recall Faraday's retort to the question ' What is the use of this new discovery ? ' ' Sir, what is the use of a new-born baby ? ' he replied. The State must shoulder a share of this responsibility. I would like to see sufficient funds put at the disposal of the trustees of science, funds which would ensure that fundamental research, as much as applied science, would be well financed. And I should like this to apply to medical and

agricultural research as well as to industrial research.

Nor must the horizons of the scientist himself be limited. If the nation is to profit from science—nay, if it is to acknowledge and repay the debt that it already owes it—it must see to it that science and scientific men have the reward which their contribution to human well-being demands and justifies.

Let us tell the tale of the progress of science and let us applaud it. In this field the British Association has done great work. In this war every soldier, sailor and airman is in constant, daily contact with the 'gadgets' of science, the achievements of the scientist, and this familiarity in its turn is breeding an understanding of what science can and must do in peace.

We can look to the future with great hopes: we do not want a brand new world but a better world: a world that arises from the roots of the past and has been refreshed by the access of much new knowledge and an aroused public conscience. It must be a world that we want, not one that is imposed on us. The omens are propitious. When I look on the vast armament of scientific knowledge which is at our hand I feel justified in my faith in the future of Britain. Let us be firm in resolution. Let us say we will build a society that will match our endurance in war and the bravery of the men who made a future possible for this country. It will be a society free to choose its own destiny but firmly resolved to remove from its midst much of the misery that has come in the past in the train of poverty, of sickness and of a failure to bring human understanding to industrial practice.

Edward Carter

Science and Housing

Most ordinary Englishmen faced with the suggestion that science has much to do with housing might raise an eyebrow. Most ordinary Englishmen live in conditions which, according to any scientific definition of social rights, are far below what should be considered tolerable. Between the wars we built about four million houses, raising our national supply from eight to twelve millions. The four million new houses were most of them traditional structures, showing practically no evidence of scientific intelligence in their construction, materials, equipment or in the building processes or organisation or in their site planning. Nor in their appearance did they show, as good scientific work must show, that sense of æsthetic integration which is the visible evidence of a completely intelligent activity.

The comparatively few advanced modern houses which showed some experimental zeal were mostly for the wealthier classes and must be reckoned more as exceptional laboratory models rather than as parts of the mass national housing achievement. The great deadweight of the 8 million pre-1914 houses are all at least 30 years old, and it has been calculated that 4½ million are over 80 years old, over one million more than 180 years old and 36,000 over 250 years old. What other social service could carry that dead weight of antiquity?

It is sometimes believed that we are alive to our housing problems. Certainly we talk a great deal about them, but the quality of social conscience is to be reckoned not by what the intellectuals preach or the people want but by what the community achieves in the actual business of life. On this estimate we have failed. Many things are needed to assure success: one of them is the use of the resources and the methods of science in our attack on every part of the problem. It is useless to pretend that we realise that there is a housing problem until we are, in actual fact, some way on the path to the realisation of the solutions. In this, science, along with her sisters the arts, has a vast part to play. Any consideration of housing, and particularly of science in housing, if we consider it as we should, as primarily a social problem, is consideration of potentialities rather than actualities. That, no doubt, is why housing is in the section of this Conference on what science might accomplish.

All of us here, I expect, live in houses where, on a simple technological basis at least, there is evidence of a background of science. Taps turn and produce water, hot or cold; windows keep out the rain; wall surfaces are superficially hygienic; materials are durable; and there may even be someone here who lives in a flat with tolerable acoustic conditions; but it cannot be said that even in the best houses science has been displayed in more than a hit-and-miss, Jack Hornerish manner. It cannot be said that even if science has had some recognition in the more expensive houses it has had any at all in the houses lived in by people with lower incomes than the best. This existing hit-and-miss pseudo-science is not what we are discussing here. Science is not in housing at all until it reaches and enlightens the problem for the mass of the people. Nor is science, in the terms of this conference, the casual and unplanned overflowing of basic scientific work in a trickle of techniques and ingenious contrivances. We are concerned with science as a pervasive, continuing, and strenuous effort to analyse, co-ordinate, solve, and achieve. What then, can scientists do about it? If this conference succeeds in making more people realise that there are scientists willing to help, what help can they give when they are called on? What are they doing now to justify popular confidence?

There are three broad divisions into which I would divide the scientists' contribution.

First, and most fundamental, we have to get a definition of the problem itself. Second, we have to provide solutions, bring all our techniques, material and equipment to a high pitch of efficiency and to co-ordinate them into integrated designs for dwellings and communities. Finally, we have the operations stage. The war has shown convincingly how much science can contribute to 'ops.' Housing 'ops' is a business of economics, scientific management, production and job supervision. In all these three parts science has a vast and hitherto largely unused contribution to make.

The first section provides perhaps the most immediate and the most fruitful field for large-scale and concerted scientific effort. The task is simply to give an answer to the question, what is the housing problem? What do people need? What do people want? We have pretended that we know the answers, but the pretence is merely due to a rough and ready idea that because everyone lives in houses everyone must know what a house should be. We do not know the answers, at least not with the scientific accuracy needed to tackle the problem correctly, chiefly because practically no one in Britain has sufficient actual living experience to tell what he wants. A lack of experience can also deprive people of the best of all impulses to get on with the job. Lacking real knowledge of the problem, we have fallen back on a weak policy of technological *laisser faire*; a hope that industry, directed by profit-making motives, will produce the right materials and equipment at the right time; but the industrialists as much as the scientists need the direction of accurate social science.

A disability that is perhaps even more at the root of things is the still surviving social division between the 'housers,' as the Americans call housing specialists, and the housed. Almost always it has been a matter of people debating how to house a great amorphous 'them.' Do 'they' like cupboards? Do 'they' like parlours? Do 'they' suffer from bugs? Do 'they' keep coals in the bath? It is one part of the community trying to house the other and the bell does not ring true.

I believe it is possible for there to be what almost amounts to an intuitive understanding between the technicians and the people they serve; but to achieve that we must have a complete and inalienable, classless, social association between the technicians and the mass of the people, such as we have not yet achieved. In the past it has been achieved in many simple and in some fairly complex societies. It has existed wherever a genuine 'architecture' has appeared and it existed in the aristocratic limited society of the Renaissance. I believe that somewhat the same co-ordination is now being achieved in the USSR. To-day this instantaneous awareness cannot be attained in a flash. Now we have to analyse and reason our way up every step, and translate our conclusions into a rationally conceived but none the less popular programme. That last phrase means that we have to adjust our programmes not only to scientifically ascertained needs but also to equally scientifically analysed wants, emotional desires. Our Chairman came across many problems of this sort in changing the feeding habits of Britain. Common or domestic man changes his living habits slowly, and there is resistance to any technical advance in house design which suggests or compels the adoption of a modern way of life in the home. Most individuals have their physical and emotional needs wrongly stressed in relation to each other, and the habitual ways of living in our dusty outmoded dwellings are at variance with both. What can science do to help?

The first need is for a huge extension of scientific survey of the attitudes of people to their domestic life and equipment; of the dynamics of family living, that is of the way people spend their time at home, how they use their houses, and, finally, of the objective factors of housing problems, of the physical factors that govern house plan and equipment sizes and shapes. One of the finest and least known scientific activities in England now is concerned just with these things. The Ministry of Information's Social Survey is busily engaged on the social science problems of housing and has contributed substantially to the background which the physical scientists and the technicians need for their work. The first detailed description of the work of the Survey was given last May by Mr. Dennis Chapman in a paper to the R.I.B.A. which was published in the R.I.B.A. journal of June last.

Perhaps the most significant evidence of the new awareness of the value of the social scientists' contribution can be seen in the work of the territorial planners, particularly in the great series of plans prepared under Professor Abercrombie's guidance, which, despite delay on the part of Parliament to provide adequate machinery for their implementation, are surely mapping the growth of our cities. Out of this work, here and in America, an old concept of neighbourhood and community is being rejuvenated as a great and real contemporary dynamic. Through the social sciences the housing technicians and planners are being enabled to solve real and not idealistic problems and are beng enabled to apply their services efficiently. A social pattern for English life is being evolved inductively which should have vast political consequences.

What of the next stage—the provision of practical solutions to the design problems? What are these problems? The simple definition is an old one: firmness, commodity, delight. Our houses must be stable, sure in their resistance to the elements, well accommodated to the lives of the people in them, comfortable and commodious, quiet and well-equipped—and all this integrated into an æsthetically satisfying form.

In June last year Mr. Anthony Chitty, one of the fine team of young architects whom the fortune of war has drawn into public service, read a paper to the R.I.B.A's Architectural Science Board on this part of the contribution of science to housing to which I refer anyone interested, for a far more detailed survey than I can give in a few minutes. There is being made now a vast and reasonably well co-ordinated attack on the fundamentals of good building, the results of which will make all our building byelaws and almost all our pre-war text-books out of date. The Minstry of Works' Post-war Building Study and Codes of Practice Committees, the various housing committees of the Ministry of Health and the Scottish Board of Health and the professional societies of architects, engineers and surveyors are working together with almost the total resources of the Building Research Station of the D.S.I.R., to redefine almost every scientific and technical problem of housing in the terms of standards of amenity, of health and welfare.

The first range of problems here covers naturally those of structure: how to build well, to give strength and stability, to protect from the weather and noise and to give good ventilation. We have lacked scientific disciplines in our use of materials old and new. The old techniques are ill-adapted to the new materials, and recent research has

frequently completely changed our use of the old materials. These can only seldom provide economic solutions to problems as large as those we are facing now in mass housing.

The central problem is that of the house wall and roof. Traditional methods of design rely on solidarity and weight. The new materials and the new use of some of the old materials have made possible the building of light-weight structures which are stable enough to hold up but fail to give adequate thermal or acoustic insulation. Millions of people in the speculative builders' houses of the past twenty years have suffered from unscientific light-weight building, and millions more from shoddy traditional building.

'Now that science has enabled us to analyse the physical characteristics of building materials, we can preserve the efficiency of a slender and economic structure and use suitable insulations as coverings and fillings to reduce the transmittance as required. Released from the need for carrying loads, the wall panel can now be perfected as macintosh, insulator and interior finish, performing if expedient all three duties at once in sandwich form.' Almost the chief importance of the present work, Mr. Chitty indicates, is not that it suggests that house standards can be raised, vastly and immediately important as that is, but that even the comparatively small amount of research undertaken so far points already to almost unlimited possibilities of advance; and he lists various problems which can engage the scientists fruitfully in the future. And now, we may remind ourselves, the building scientists can count on the fundamental direction which the new applications of the social sciences can give to their work. The purely weight-carrying functions of walls and floors are the least of their tasks. They are the essential protective elements, dividing inside from out, stabilising the interior climate, however fickle the climate outside, protecting the users of one room and their various occupations from those in the next room. None of these things are well done in any houses now, but they can all be well done if the social system is adjusted to implement an admission that the ordinary citizens of Britain, poor as well as rich, deserve the best that modern technology can give.

In 1939 Fitzmaurice and Allen of the B.R.S. published a remarkable study of sound transmission in building which carried our knowledge of this urgent and hitherto neglected detail of house design so far forward that we can say now that we have a solution to the noise transmission problem, if not of the problem of the noise maker. The answer no longer remains with scientists, but with economists and politicians. Similarly, and also through the B.R.S. and N.P.L. work, great progress has been made in day-lighting studies, ranging from the widest aspects of site planning, in which the scientists have co-operated with the town-planners, to detailed matters of window design. Efficient siting can be defined in terms of quiet and light, but, once more, the operational stage has hardly yet begun and is at present in the hands of business men and politicians and land owners who do not all feel disposed to accept the scientists in their kingdom. It is notorious that of all the industries in the country the building industry is one of the least well organised and least well adjusted to assimilate scientific method. Much has been learnt during the war on the techniques of job and site organisation and building supervision and present studies of prefabrication are teaching us how factory production methods can contribute to building speed, efficiency and economy. We have got to keep our eyes open to the fact that so far this experience has largely been in a form and in situations which are abnormal. There is a spontaneous social urge to reject abnormal experience —as our Chairman's successor in the Ministry of Food will probably find on such questions as brown bread—when more normal times return. Good but abnormal experience can only be retained in social routine if it is translated out of the emotional pattern of abnormality into scientific terms of analysis and organised technique. Attempts have been made to do this but even now those who can see behind the scenes are aware of some serious gaps in co-ordination, sometimes a lack of goodwill and everywhere a lack of really competent trained personnel to fulfil this process of scientific analysis and co-ordination.

The operations stage of housing, is of course, the one most in the hands of the politicians since control of buildings will certainly remain one of Parliament's first responsibilities. In the opinion of many without such controls no scientific organisation can possibly be achieved with an efficiency up to the demands of the problem.

The Building Research Station is now conducting research into what might be described as "the man on the job," studying the actual efficiency of the building operation down to the smallest detail. Out of these studies no doubt will arise important guidance in the organisation of building trade education, which still remains mostly on a traditional and craft basis. Their research so far has shown the enormous importance of supervision as the scientific and technical organisation of building is improved.

This brings me to the last of the three sections —the 'ops' end. The scientists have now shown clearly what science can accomplish within the limited range of problems which they have been enabled to tackle. They can enlighten our understanding of the very roots of the housing problem by revealing accurately what are the fundamental needs and wants of the people. In the technical problems of house design and the related problems of siting they have carried us forward in all but the doing of the thing to the threshold of a new world built on the sure foundation of a decent dwelling. The scientists are not happy in working, as mostly they have done in the past, to make low standards tolerable; nor for long will they be content to design high standards which cannot be translated into the real life of the mass of the people. They know that in this last stage too they have things to offer to assist the fulfilment of plans with scientific efficiency and with social enthusiasm.

Sir Joseph Barcroft, F.R.S.

Food

THE progress of science is incalculable—'the wind bloweth whither it listeth'—but we can

rely upon its continuing to blow, and if, as a minimum, we assume that it will continue in its present direction, we may project the past into the near or less near future.

The object of food is human nourishment. The more exact our knowledge of the needs of the body, the more exact will be our capacity to estimate the quality and the nature of the food we require. Great indeed have been the advance in the 25 years between the two wars in enlightening us about what the body needs. In 1914 we regarded our needs solely in terms of calories and nitrogen—so much carbohydrate, so much fat and so much protein, and the matter ended with ascertaining the necessary coefficients and the degrees to which the above proximate principles were interchangeable. Almost within the span of the inter-war years the whole range of vitamin research has been carried out. Many, indeed, have gone to the other extreme and think now of nutrition solely in terms of vitamins, forgetting the calories. That will pass. The point is that on the basis of the new knowledge a robust nation is rising up. That is true in varying degrees in all classes of life. Even among the 'well-to-do' in my youth there was plenty of C3 standard which was due to ignorance of the basic principles of diet. But naturally, it was among the poorest, and those whose nutritional requirements were greatest—e.g. children—that these deficiencies were felt most, and among whom the dawn of new knowledge has produced the most encouraging results.

Although we have broad pictures of the effects of diet on growth, and some considerable knowledge of the relation between diet and disease, yet there remain numerous questions : variation in individual requirements, long-term effects of nutrition on health and on what might be called vitality.

But where do we stand with regard to the nourishment of a man's brain? In terms of chemistry, what are its activities and what are its needs? We do not know. The sudden increase in what we expect of our brains has always seemed to me only less remarkable than the response they have given. The human body and mind has been evolving for thousands, not to say hundreds of thousands of years. Now in a century comes the change ; we expect little more of our bodies, but what about our minds? Two hundred years ago man was mostly agricultural, he tilled and passed an occasional thought through his cerebrum as he did so. Now it is think, think, think ; add, add, add—all day and perhaps seven days a week. How can it be expected that a machine which in the course of evolution has only faced so limited a load can now be driven so hard? We are getting to know something about the relation of mental breaks to deficiencies of this or that in the blood. Can this be the dawn of a day which will place the nourishment of our central nervous systems on an ascertained basis?

It may be that within a decade much of our so-called knowledge will be regarded as intelligent guessing, for we have a new engine for the study of the fate of food within the body. I refer to labelled elements. Already in the sphere of carbohydrate metabolism their use is remoulding our ideas upon what happens to important articles of diet. I foresee that within ten years a great change will occur with regard to the certainty of our knowledge of the relation of food to man.

During this war the health of the country has improved in spite of deprivation of foodstuffs both in quantity and in variety. This has been accomplished by increasing the effectiveness of the ways in which the limited food resources have been utilised, and there is no doubt that the success achieved must be ascribed in part to the development of administrative technique for bringing into application the existing knowledge of food and nutrition in amounts to satisfy physiological requirements. Moreover, the principle has emerged that shares are only fair when the nutritional needs of each 'sharer' are taken into account. Here, surely, we have reached a position of vantage from which we need not recede.

Let there be an abundance of scientific laboratories in the country carrying out research untrammelled by thoughts of its application. Let there also be a body which dictates policy, long-term policy no less than short-term policy—that is to say, a body whose business it is to know just what the country can get, what the country needs, and by comparison, what needed commodities the country lacks. These two organisations, that which dictates policy and that which works only at abstract science, are so remote the one from the other that they are in danger of never meeting. Between the two there must be a chain of scientific work at one end of which is abstract knowledge, at the other food : food made from the most satisfactory materials, treated in the most satisfactory way and delivered at the most satisfactory time, at the most satisfactory price and in the most satisfactory form. I stress the question of price a little, because the question of what a family can get depends upon what they pay for. A start has been made with all this under war conditions, necessarily short-term and imposing artificial limitations, the paramount object being victory. Under such conditions the public desire cannot make itself adequately felt : the public has to eat what it can get, and may be extremely thankful to be able to get it. They can be extremely grateful for the food they have. Let us look forward, however, to the day when the public can voice its likes and dislikes. Uneaten food has no nutritive value, and even food which is eaten and disliked is a doubtful proposition from its nutritive point of view. The whole subject of flavours, their chemistry, their physiology and their significance, seems to me to demand investigation. They have constituted the principal guide which mankind has so far possessed ; what is their real value? How much weight should the man who dictates policy give to the factor of public taste?

In my work for the Agricultural Research Council I am confronted with many questions of policy on the solution of which depends economy of effort. What is to be our milk policy? What is to be our beef policy? What is to be our pig policy? What is to be our egg policy? When we know the answers to these questions we will know into what channels to divert our research.

I will take milk as an example of the rest. The country has become more milk minded to its great advantage. In spite of rationing there is considerably more milk drunk in Great Britain now than before the war. In Northern Ireland, where milk is not rationed, the consumption has risen from 14 million gallons to 32 million gallons—a rise of 130 per cent. Doubtless a bias exists in favour of milk because other foodstuffs are rationed and milk is not: even so, the rise is very remarkable and is increasing. Are we in England going to concentrate on milk production or are we going to meet the demand by importing milk in various forms? If we are going to concentrate on milk production, research must take the form of increasing the milk yield of our herds, which at once opens three doors—(1) research in breeding, (2) research in feeding stuffs, and (3) increasing the output of milk per cow. Research in breeding introduces the whole question of artificial insemination. Research in feeding stuffs raises another question of policy—do we intend to import our feeding stuffs or to grow them? If the latter is our intention we should endeavour to get breeds of forage of high protein value. It is idle to tell the farmer to grow beans when we know the bean crop to be so precarious that at harvest the beans are unlikely to materialise. Lucerne has this great advantage, that it will fix the nitrogen from the air, so that the only dressing which need be imported for it is phosphate. I think that is approximately true, although I would not say it was 100 per cent. true. It would be for the plant breeder to secure for us strains of lucerne which are adapted to the soil and climate of this country. And while I am talking about the plant breeder, there are other objectives which we might follow. There is the whole question of breeding foods suitable for processing. Let me take an example, though it is not one which touches plant breeders in this country. The peaches of choice flavour tend to become a mush when canned, the peaches which stand up physically to canning are of inferior flavour. Here is a problem for the plant breeder. And remember that man's diet depends in the end upon agricultural production and, as in the past, so in the future, improvements in his diet will depend primarily upon improved efficiency in the agricultural production of more and better food. The work of the plant breeder is one offering enormous long-term scope. Think what can be done if the breeder sets himself to producing not merely varieties which yield bigger crops, but crops of improved nutritional value and specifically adapted to particular uses—for example, carrots with more carotine.

But to return to protein for dairy herds. If we are going to import our protein, then the whole question of yeast products arises. What are the prospects, say in Jamacia, of yeast producing protein at a price suitable for cattle feeding?

Why you may ask, is this emphasis put on, protein? Here again is a subject for research, but the indications are that it is easier to prevent the dairyman watering the milk, than to prevent the cow watering its own milk. The problem is not merely to increase the quantity of milk which a cow gives, but to do so without letting down the quality. There are ways in which the milk yield of cows can be increased; indeed, worth-while qualities of milk have been obtained from cows which have not come into calf and from barren heifers. These methods depend largely upon advances in our knowledge of hormone physiology. Large-scale tests are recorded in a remarkable series of papers (*J. Endocrin.* 4, 1-102) from the Dairy Research Institute at Reading, from the Animal Nutrition Institute, Cambridge, and from the National Institute for Medical Research. Some of their methods, whilst producing the milk, at present have drawbacks rendering them unsuitable; they tend to oversex the cows in ways inconvenient to the farmer. Further investigation might well overcome these difficulties. The necessary experiments, however, require a great number of cows and are very expensive. Should they be undertaken? That depends on policy.

Should policy dictate that pasture be kept to a minimum and that we import milk? Research must ascertain how this can best be accomplished.

You may say, why stress policy so much, why not carry out work in all possible directions and let those who dictate policy pick what they want out of the pile? I have already tried to forestall this question by using the phase 'economy of effort.' But if I am to strip that phrase of its administrative flavour, or as the phrase goes 'debunk' it, its essence consists in the fact that there are not the workers, especially at the highest level, to carry on indiscriminate research at the present time. It is my privilege to deal with the future of various research organisations: we say, 'let us put a really first-rate man here,' or 'all this place wants is three really first-rate men in key positions,' and the like. But at present there are not enough of these first-rate men to go round. It should be a matter for future policy not only to dictate policy but to give encouragement in careers.

I have spoken of food for the brainworker and for farm stock. May I end on a note which touches both the dietician and the farmer?

In the case of man I have admitted by implication that we know a good deal about the dietetic demands made by heavy muscular labour, and I have held out some hope about the special requirements of the brain worker, but I have said nothing about the specific needs of the organism—human or animal—when bearing young. Here is an almost unexplored field; yet what could be more important? In the past we have done little more than guess. Now a start has been made both across the Altantic and in this country. We are ignorant, for instance, on such a fundamental question as whether the needs of the mother simply grow *pari passu* with the growth of the foetus or whether they ante-date that growth. Should we fortify the mother beforehand, and if so with what?

When science satisfactorily informs us on the nutritional demands of these three great forms of activity muscular exercise, mental work, and maternal potentiality, we shall have made a real start along the road to rational, shall I say functional, nutritition, a road towards which our Chairman's own legislation beckons with a beneficent finger.

Prof. J. M. Mackintosh

What Preventive Medicine might accomplish

In addressing his students one of the leading anatomists of the early nineteenth century offered the following illustration. 'Anatomy may be likened to a harvest field. First come the reapers who, entering upon untrodden ground, cut down a great store of corn from all sides of them. There are the early anatomists of modern Europe, such as Vesalius, Fallopius, Malpighi, and Harvey. Then come the gleaners, who gather up ears enough from the bare ridges to make a few loaves of bread. Such were the anatomists of last century—Valsalva, Hunter and the two Monros. Last of all come the geese, who still contrive to pick up a few grains scattered here and there among the stubble and waddle home in the evening, poor things, cackling with joy because of their success. Gentlemen, we are the geese.'

The author of this sally of wit saw only one narrow strip, when (as Osler pointed out) the broad acres of biology lay open before him. Perhaps we are less myopic to-day, yet only a few weeks ago a medical writer made this rash prophecy about surgery: 'Though surgeons are as busy and as necessary as ever, surgical science is nearing completion.' It is probably more true to say that surgical science is still in the clumsy experimental phase of its childhood, and that preventive surgery has only just begun to take shape. The recent advances in plastic surgery, for example, are not merely refinements in technique but the progressive application of new biological knowledge; and recent work on the lungs, the nerves, and the blood vessels opens up great highways for the march of science. Surgery has lately secured a powerful ally in biochemistry, and increasing safety in the operating field should lead to bold adventures in the use of mechanical devices for the repair of tissues. We badly need the mechanical expert in the surgical repair shop, and we must call in the chemist to help us in the search for non-irritant materials which can be used in surgical architecture. I look forward confidently to the time when the 'foreign body' will be a friend, and when the restoration of the disabled will reach a mechanical and functional perfection undreamed of to-day.

Turning to preventive medicine, we must first recognise two broad divisions of the subject: the environmental, represented by sanitary science, housing, town planning, and the like; and the personal, with its family and social background. Sanitary science made great strides in the latter half of the nineteenth century, and some progressive areas reap the benefit in a good and abundant water supply and efficient drainage. Yet these advances were hardly more than pioneer demonstrations. The immediate blessing that sanitary science should bestow is to make living more gracious for the whole community. Its future flows along the pipe and the wire, and its secret is *water*, first of earthly singers. Water is the treasure house of health and the good life, yet here we are, even in some of our great cities, eating soap by the ton and drinking other people's bath water, furring our kettles, and ruining our clothes and our boilers—when within easy reach abundant supplies of clear soft water are waiting to be gathered. Here we are, in the year 1945, with the pitcher still going to the foul well, and typhoid lurking in the crevices of our gathering grounds.

The giant power of water is better utilised than its other virtues, but we still lag far behind in the provision of cheap supplies of electricity to home and factory. Meanwhile we misuse coal by allowing countless chimneys to pour their smoky filth into the atmosphere. It is the urgent duty of sanitary science to apply technical knowledge to the practice of health, and smoke prevention is one of its immediate tasks.

On the personal side preventive medicine stands at the door of opportunity. The brilliant discoveries of bacteriology and biochemistry are too narrowly limited in their distribution, and they have yet to be fully applied to prevention. Our methods of introducing biochemical and immunizing substances are clumsy: we must bend our energies to the study of the respiratory tract as the receptor of measured and graduated doses of protective material. It is notorious that doctors tend to escape infections such as influenza, in which their can be no question of lasting immunity; and the simple explanation is that in the course of their daily rounds they received immunizing doses of the infecting organisms by way of the respiratory tract. In recent years we have learned a great deal about the production of mists of fine droplets; we can regulate the size and rate of flow, and we already know something about their course and distribution when introduced into the human body. Further, we are learning how to charge these droplets with protective materials in a suitable form, and it is but a short step to gain scientific control over dosage. Generations to come will smile indulgently when they think of our crude methods of blood transfusion; but they will remember how these methods saved innumerable lives.

In the battle for preventive medicine we have been strangely content with numbering the dead. More effort should be spent in counting the wounded. Science cannot help us as it should, unless it is provided with the raw material—the numbers and the causes. Count the syphilitics and you know what the problem is; talk cotton-wool about them and you will not. To know the extent of your task is the first step in prevention. Otherwise, 'where your mind should go straight, it will dodge; the difficulties it should approach with a fair front and grip with a firm hand it will be seeking to evade or circumvent.' For some years past the Department of Health for Scotland has been making serious attempts to analyse the causes of disability among industrial workers, and the recent Clydeside experiment is the logical outcome in preventive medicine.

In the strategy of prevention science can help both in the study of the campaign as a whole and in directing the spearheads of local action. Taking the latter first, tuberculosis provides me with a convenient illustration. Here is a problem of specific infectious disease against a broad social background. It is not enough for one body of scientific workers to study the infecting agent, another to deal with early detection and treatment, and a third to tackle housing, industrial

conditions, and so forth. There must be a concerted attack in the name of science. Let me illustrate this principle in another way: in the Tennessee Valley the creative work calls for men of many different kinds of professional and technical experience: geologists, agricultural and forestry experts, chemists, architects, doctors, engineers, and many specialists of more limited scope. Even under the best conditions it is not easy for each specialist to estimate the importance of his own job in relation to the work as a whole, and specialists are seldom trained to look beyond the wild wood to the wide world. 'It is an ironic fact,' says David Lilienthal, 'that the very technical skills which are employed to further the progress of men, by the intensity of their specialisation create disunity rather than order and tend to imperil the whole success of their common objective. Resources cannot be developed in unity until each technologist has learned to subordinate his expertness to the common purpose, has come to see the region and its problems in their entirety.' The problems of power, flood control, conservation of soil, prevention of malaria, and general welfare march shoulder to shoulder, and the decision to be taken on any issue has to be the one which will yield the best results as judged by the common purpose—the health and well-being of the people. It is in this spirit that science must tackle the public health in our country. It is not within my sphere to deal with food or housing, but surely there also lie the foundations for a common purpose in which the State, the man of business, and the scientist must join. With preventive medicine in general, both personal and environmental, the same principle of unity holds firm.

In this age of destruction we are deeply concerned with the more positive aspects of prevention—the promotion of health. How can science help? The answer lies, I think, in the integrating concept of social medicine, the study of man in his environment—the individual and his family, his house, his food, and his work. Let me take work as my example. Hitherto, the promotion of health in industry has suffered from two great limitations: it has been confined for the most part to the larger factories and so covers only a minority of workers; and it has failed as a rule to bring together the vital elements of industry to create a compound of safety, health, and welfare. In both respects we have been feeding the fat with the cream and the lean with the skim milk. Naturally enough the big firms with immense resources tend to have the highest standards of health and welfare, and they are often the most strict in their rejection of the unfit. The firms which have least need of salvation are the most frequently inspected. The consequence is that the smaller industries have to be content with relatively inferior human material; they have not resources enough for good social services; and they are liable to fall below even the minimum standards laid down by the Factory Acts. I am not blaming the smaller firms, nor the larger; but this is a prime example of lack of scientific organisation. They that are whole get all the medical attention. There is need for a new spirit of health organisation in industry, especially for the benefit of the smaller occupations and the widely distributed activities of transport and service. This is in itself a scientific problem, but in the narrower sense there is abundant scope for a fresh scientific approach to the whole question of health and welfare in industry, and the physician is only one of many partners in this enterprise.

I have left the most fascinating chapter in the story to the last. In the application of science to international health quarantine still plays an important part, but the whole scene has changed. Diseases such as malaria and yellow fever are no longer limited by time and space in this skrunken world. An infected traveller may reach this country by air with all his sins upon him; or he may be apparently recovered on arrival and subsequently go down with a relapse, passing his infection to a legion of local anophelines. The Aedes Aegypti, once infected by the virus of yellow fever, may carry the unwelcome guest for life, and has no difficulty in becoming a stowaway in an aeroplane. Or a dangerous vector may be brought into a country and, multiplying there, may spread a local disease. The risks are enhanced when travellers visiting endemic areas have been immunised by vaccination.

The insect-borne and tropical infections are not the only physical ills demanding international scientific control. As W. A. Sawyer says, 'A dying man with a weakened heart and swollen legs, a sufferer from beriberi contracted by eating over-polished rice, is just as much the victim of preventable disease and community neglect as if he were succumbing to cholera or typhoid. . . . After a prevalent nutritional deficiency has been investigated and identified by the health authorities, the correction of the causes in the community often involves co-operation with agencies interested in economics and agriculture. The responsibility for the trouble is frequently shared by other countries and international co-operation is therefore necessary.' Dr. Sawyer believes that the future of international health depends on the skilled distribution of current information about epidemic and other diseases, the provision of facilities for education in public health, and above all, the international control of disease, wherever it is discovered. 'As such control will be of universal benefit, we hope that it will be fitted into a world plan, formulated internationlly, and that expert or financial assistance, needed by the international health organisations in any country, will somehow be made available by the central organisations. It is of world-wide importance, for example, that the control of yellow fever should be centered in the endemic areas of Africa and South America and supported by the combined agency of all the benefiting countries. When world strategy requires that an intensive fight must be made in some country to keep it from becoming a stepping stone for a disease or insect vector, like *Anopheles Gambiae*, towards other lands, then the world should be ready to help to direct the effort to pay for it.'

Whether we ask the question locally, nationally, or internationally, the answer is the same: that science can foster progress in three main ways. It can help by universal distribution of the modern public services which are essential to the good life; by co-operation between the medical and

other technical experts, in which each is ready to subordinate his ideal to the common purpose ; and by shortening the time-lag between scientific discovery and its application to human welfare.

Prof. Sir Lawrence Bragg, F.R.S.

Our country has a fine record in pure science ; we seem to breed the right type of man and to have created the right conditions in which he can do his best work. In general our scientists are not noted for their painstaking acquisition of widespread knowledge or laborious compilation of exhaustive treatises. But they are good at breaking new ground, at having the inspiration which initiates new branches of science or solves old problems in an unexpectedly simple way. As food is so much in our minds to-day, one might say that our forte seems to be in supplying the vitamins of science, even if we are a little weak on the carbohydrates.

There is a widespread feeling, however, that we have been backward in using our scientific ability to the best purpose to strengthen our industry. The first three sessions of this conference have dealt with the application of scientific research to industrial problems, and I need not go over that ground again. Nor need I expand the theme that the future prosperity of our country depends upon even more efficient application of science to industry. This theme forms the opening paragraph of nearly every one of the perfect spate of reports and papers about science and industry which have been appearing recently. I am beginning to remark, especially amongst my arts colleagues, a distinct feeling that everyone is hearing too much about the exploits of scientists nowadays, a reaction which we must watch with care. We must not spoil a very good case by over-emphasis. There are too many things in our own house which need to be put in order for us to feel complacent. In speaking on 'What Science might accomplish,' I want in the first place to indicate what I believe to be the main 'bottle-necks' which are restricting the vitalising function of science in industrial and national affairs.

I would put as the first of these bottle-necks the fact that science is not yet a recognised part of a good general education, especially the higher education of the young people from whom the leaders of the future are likely to emerge. I was deeply struck by an article by Prof. Dobrée in a recent number of the *Political Quarterly* (October-December 1944). Under the heading 'Arts Faculties in Modern Universities,' he asks 'What do we consider an educated man?' He lists six realms of study which I abbreviate here :—

(1) The physical structure of the world, as exemplified by physics and astronomy.
(2) Biology.
(3) The large movements studied by history.
(4) The ideas and organisation of the human race ; anthropology, psychology, sociology.
(5) The basis of values ; religion and philosophy.
(6) The achievements of literature, music and art.

He calls these six realms the humanities, and I think it is most inspiring and heartening to us scientists that a Professor of English Literature should include under the first two headings the two great branches of natural science, and (under heading four) subjects with strong scientific traditions.

Are we giving our young people an education which is planned to make them realise the kind of world they are living in, as a whole? Scientists often deplore the early specialisation which cuts off young aspirants from the more humane studies, but surely the specialisation is worse in the case of the non-scientist. Most scientists I know have at least learnt enough outside their subject to be able to read history with pleasure, to feel that ideas about the basis of values provides the driving force for all human endeavour, and to follow the latest achievements of art and literature. But is this true on the other side? Our leaders in politics and industry who have been educated on more classical lines only too often think of science as a subject for experts, and of scientists as tradesmen who are to be consulted when there is trouble. But one cannot properly use an expert unless one has some knowledge of his field, at any rate enough to realise there is a problem in which he can help ; to pick the right man, to put the problem to him, and to know with what relevant information he must be supplied.

My second bottle-neck is perhaps only another aspect of this lack of a widespread knowledge of what science is and can do. There is a very general reluctance on the part of the most brilliant of our young scientists to go into industry. This has been my experience as head of a University science department, and it has been confirmed by the questions I have put to former students who have been doing war work. One would have thought that, with the experience of applied science and development they have been getting in the war, many would have become interested in the use of science in industry, but in the answers to my questionnaire not one in twenty expresses this ambition. Why? It is a very serious phenomenon.

As far as I can make out, the main reason is what is vaguely expressed by them as the 'conditions' or 'atmosphere' of industry. I think at bottom this means that their potential employers do not understand what sort of animal the scientist is, his psychology, how to keep him fighting fit and happy in his work. They try to fit him to a Procrustean bed of regular planned output, not realising that if he is worth his salt he must have something of the artistic temperament with all that implies. A mainspring of the artist's activity is to be an intimate member of a small world of experts, who can appreciate or criticise his work. How often have I heard from a past student who has gone into industry—'As long as I go on turning out results no one ever talks over my work with me or takes an interest in the scientific side of it!' Combine this with few opportunities or none to spend any time on pursuing an interesting discovery unless it has an immediate and obvious application, and one can see how the keen young scientist is apt to regard industrial research as a last resort. I do not think the main difficulty is salary.

There are of course many exceptions ; many

industrial concerns with a strong scientific spirit. One can sense the difference when being shown around an industrial laboratory. In some the scientists are dispirited, in others they are on their toes and thoroughly enjoying themselves, and I think the keenness in the efficient laboratories can generally be ascribed to there being a director who can talk to the scientists as an expert and show that he appreciates their difficulties and triumphs.

Finally there is a difficulty to which I must refer very tentatively, for its solution requires a wiser political head than mine. Young people, who incline to the left in their politics with a good deal of idealism, like to feel that their work is directed mainly by considerations of social service. They distrust the present economic and competitive structure of industry. I am not trying to judge whether they are right, I am merely reporting my impression of an underlying cause of the reluctance University teachers encounter when they try to direct their students to industrial posts.

What might be done has been shown by the war. Our best academic scientists have joined their industrial colleagues, and bent their energies towards a common end. The rate at which development has taken place along certain lines is amazing. Cannot we mobilise the same energy and goodwill for the ends of peace? We have at any rate had an object lesson of what it is possible to achieve when the application of scientific methods is given a free course, with an incentive to everyone to give of his best.

I have dwelt on these obstacles to the full deployment of our scientific forces in the industrial battlefront, because it is so important that scientists should not be discouraged by them and retreat into an ivory tower of pure research. Industry is our breadwinner. Speaking as a University scientist, I realise that our plans for a great expansion of pure research, the realisation of the ideals we set ourselves, depend in the end upon the success of our industrial colleagues in making our country prosperous and strong. This end should be a more inspiring incentive to our best young scientists than the war work in which they have proved so useful. My sense of our dependence on industry has always made me feel that any help which we can give our industrial friends, any information they require, any advice about recruits, should have a first call on the time and energy of those of us who are working in Universities.

When we ask What Science might accomplish, we must ask, at the same time, What do we wish it to accomplish? In talking about the benefits which science can bring, the emphasis is often laid in the wrong place or perhaps it would be more correct to say that the means are mistaken for the end. Science confers a greater power over nature. It can be used to increase material comforts and standard of living, to provide power and light, better houses, better means of transportation and communication. It can be used to fight disease. It can relieve from drudgery and increase leisure. But these are not ends in themselves, they are only valuable in so far that they make it possible for many people to live a better life. The things worth having are a delight in the craft by which one earns one's living, and an increased power of enjoying cultural activities. If we insist on the material advantages which science brings in its train as an end in themselves, we will have our humane colleagues with their 'basis of values' on our track, and they will have justice on their side. Our answer must be that the higher achievements of the human spirit are based on the foundation of man's command over nature. The wider and stronger the foundation, the higher the edifice which can be built upon it. The material achievements which science makes possible, rapid communication and travel, power, command over materials, are making the world a higher type of organism with a more complex nervous system and greater division of function. Though it is only too obvious that the new powers can be used for evil as for good, it would be a counsel of despair to refrain from developing them on that account. It is not in any event a matter of free choice what we do. We must use science to the fullest extent because we are being swept along in a great world movement. A widely diffused understanding of science is the best safeguard against its abuse.

Sir Harold Hartley, K.C.V.O., F.R.S.

We have had a series of addresses, the interest of which has been greatly increased by their high diversity factor, and it is just that factor which makes my task of trying to sum up the Conference in a quarter of an hour almost impossible.

My mind goes back to the meeting of the Council at which this Conference was born. Sir Lawrence Bragg has said that there has been a spate of statesmen's speeches, reports of committees and conferences, most of which suffered because they represented only the greatest common measure of their varying opinions, but there has not been a gathering of representatives of science and industry to discuss publicly from their experience the place of science in industry. That was the Conference which the Division decided to call. Its objects were first to give the public a clearer realisation of the way in which science contributes to industry, and secondly out of the discussion there should emerge, we thought, a clearer view of the strategy and the tactics of science in industry.

Our first session was on what Industry owed to Science, and we had a most salutary opening which removed any danger of complacency. Lord Brabazon reminded us that the greatest achievement of our time, the achievement of flight, came not from scientists but from the owners of a bicycle shop. But that initial achievement, as he pointed out, gave at once a great impetus to an immense range of scientific work.

Sir Robert Watson Watt turned the tables by asking what science owes to industry, quoting the critic's view that science makes securities insecure. so there was no danger of a Narcissus complex developing at this Conference.

As the session went on certain general agreements which were expressed in different ways emerged: the realisation of the dependence of industry on science and the way, as Mr. Bevin put it, in which science is dominating industry; Professor Bernal's view that science and industry

are not two different things but two aspects of a process; and Sir Robert Watson Watt's that science in industry is really a state of mind because the use of science must become the normal practice of industry.

Again, in summing up, Professor Bernal contrasted the newer industries born in the laboratory with the older industries, some of which have not yet recognised the need for change, and he pointed out that there had been no comprehensive scientific study of what is the proper relation between science and industry. It was necessary to determine what was the best working partnership, how their collaboration could best be secured, and he suggested the need for an objective analysis of that question.

How far has that question been answered in our discussion?

In the next session, on Fundamental Research in relation to Industry, Professor Blackett threw a great deal of light on it by his contrast of fundamental research as a long-term investment, chancy but with great prizes, with applied research directed to a definite aim, a short-term investment giving immediate returns, not perhaps so large or spectacular. The proper balance between the long and short period investments, fundamental and applied research, must, of course, depend on circumstances; and, as he pointed out, in this war the whole of our effort has been thrown over to the side of applied research. But in normal times fundamental research is essential, first for supplying the basic knowledge for further advances, and secondly as the training ground for future research workers in applied science. He suggested that the immediate goal of applied science after the war must be improved methods of production of consumption goods, rather than improving the goods themselves, leaving that improvement until the time when all the immediate needs have been met, the main objects of science being to raise the standard of living and to help to secure stability.

Other speakers in the session on fundamental research gave an impressive series of examples of the enormous effect that fundamental research has had recently on industry in various ways and the wide possibilities which are opened up by it; for instance, Dr. Darlington pointed out the great prospect of the control of living processes, of disease and genetics.

That was the session of the scientists. Then came the turn of the industrialists in the session on Industrial Research and Development. They gave an extremely impressive record of the application of science in industry from which certain impressions emerge. First, they showed that in the industries for which they were speaking there is a developed technique for the application of science in industry. Of their conviction of the essential importance of fundamental research, they spoke as strongly as the scientists, and, in particular, Mr. Devereux drew our attention to the need to safeguard the absolute freedom of fundamental research and to see that in the universities there was no encouragement of applied research which would hamper in any way the opportunities for fundamental work. Then they stressed the need for close collaboration between scientists and engineers, both the need for good team work, and the need for a better understanding of scientific work by the production engineer. They explained to us the part played by science in different industries, in new inventions, in the development of processes, in new machines, and in the control of production; and science was called by Sir John Greenly the pathfinder of industry.

When that session was finished we were asking ourselves, as Sir Lawrence Bragg said, is all as well as would appear from the addresses we have listened to? I agree with him that the speakers were a hand-picked bunch and came from firms to most of which the war had given a great stimulus, and that they are not altogether a fair sample. Indeed, Sir John Greenly had warned us that there are industrialists who hesitate to encourage scientific methods, and fail to support research departments and contribute to research associations. Mr. Devereux, as well, pointed to the lack of enterprise in the application of discoveries and to the shortage of trained scientists, and showed how much the awakening is due to the stimulus of the war. You remember Dr. Johnson's phrase when someone expressed surprise at an excellent sermon preached by a parson from the condemned cell at Newgate: 'Depend upon it, sir, when a man knows he is to be hanged in a fortnight it concentrates his mind wonderfully.' There is no doubt that the element of danger has contributed much, as Mr. Devereux said, to that great development we have seen in the last few years, and there is the question, will it last? In spite of these encouraging addresses I think we must be very careful in indulging in false optimism, and I do suggest that there is a need for that objective analysis of which Professor Bernal spoke. Perhaps our Chairman may view this need as coming even within the sphere of reconstruction.

We need more money, more general appreciation of what science can do, and many more technicians. Mr. Bevin told us what he had done to meet the latter need during the war. We know his interest in the problem on which Lord Hankey's Committee has just reported and his determination that the trained intelligence and ability of this country shall not be wasted, and in future shall be directed into the right channels.

We now come to our last session. It has been a great encouragement to us that for the second time we have had a Minister of the Crown in the Chair, to show the interest of the Government in this problem. It was particularly encouraging to hear Lord Woolton speak with such conviction of the contribution science has to make to this country, and all that it can do to shape its future pattern. He spoke of the need for a new outlook towards science and the responsibility of the State and industry to see that it has adequate support, and his sketch of the possibilities showed how alive he is to the task that faces us. His words were emphasised and expanded in the addresses in this last session which showed the vast field for scientific work that lies ahead, in giving the people the food, the housing and the health which will be a permanent national investment of inestimable value. Mr. Carter, Sir Joseph Barcroft and Professor Mackintosh gave us a moving picture of the wide prospects that lie before us and the high opportunity for the social scientists and

technologists. Sir Lawrence Bragg reminded us of some of the difficulties and the bottle-necks. I was once a teacher, but I only taught chemists, and I must say that amongst them I did not find the same reluctance to go into industry as he finds among the physicists. In spite of these bottle-necks I hope we can finish on a note of optimism.

I am sure we can claim that this Conference has achieved something, for which we are grateful particularly to the Chairmen and the speakers who have made it a success. It must help towards a more general realisation of what has been done and what still remains to be done, so that in the years to come the energies and brain power of this country will be so harnessed that science will make its full contribution to increasing the prosperity, the standard of living, the happiness, and the security of this country.

APPLICATIONS OF SCIENCE

It is the first function of the British Association for the Advancement of Science to promote general interest in science and its applications. It is common knowledge that the results of scientific research have come within recent years to affect more and more closely the whole life of the community. But it is not common knowledge how extensive is the range of benefits which science offers to humanity. In the belief that a widespread interest in these matters exists and should be met with authoritative information, the Association has undertaken the publication of a series of articles designed to show, summarily and simply, how science lends a hand in various aspects of common progress. Some of these articles appear below, and it is intended to issue each of them, and others later, in separate pamphlet form as circumstances permit.

FOOD

By Professor J. R. Marrack

The food that we eat is broken down in our digestive tracts; absorbed, built up again into complicated compounds that serve a variety of purposes, broken down again, and the greater part burnt and excreted. The whole process, which is covered by the word 'metabolism,' is continuous and no part can be isolated from the whole. But if nutrition is not to embrace the whole of chemical physiology it must be limited to questions of supply. What food is needed? How much? How are the requirements affected by external and internal conditions? How can the quality and quantity of the food supply affect health and activity?

Throughout its life an animal derives both the material for the structure of its body and fuel to supply energy for its activities from its food. Although animals, man in particular, are extremely adaptable, the quality and quantity of their food must be one of the major factors that influence their health and efficiency. The degree and complexity of this influence cannot be appreciated unless the complexity of the processes for which food is needed is realised. Simplifications may be introduced in guides to action, but they, inevitably, give a false perspective.

How Food is Used

Fuel

The chief foodstuffs of animals are plants and their seeds, other animals, eggs and milk. From the oxidation of these foodstuffs animals obtain all but a negligible fraction of the energy needed for all their activities. The bodies of animals cannot be regarded as heat engines; they do not convert the energy of oxidation into heat and then transform part of this heat energy into work, but rather the reverse. However, as in a heat engine, the efficiency (in the mechanical sense) of the machinery of an animal's body is limited; the ratio of heat evolved to work done is never less than 3. The energy of oxidation of foods can be measured only in terms of heat, and all the energy expended by an animal as heat and work can also be measured in terms of heat. It is therefore usual to use heat units in measurements of the energy that animals can derive from food and in making a balance sheet of energy supplied and energy expended. The unit used is the kilo-calorie; that is, the amount of heat needed to raise the temperature of a kilogram of water by one degree. Physiologists commonly call it a Calorie, which should be written with a capital C to distinguish from calories as defined by physical chemists.

Since thermodynamics takes no account of intermediate processes, the final balance of intake and output of energy by an animal's body is similar to that of a heat engine, and comparison with a heat engine has been very useful in explaining this balance to those who were not familiar with the ideas of energy balance. But a heat engine commonly uses a limited range of similar fuels; it is possible to work out the supply of fuel needed for a given performance in terms of weight or volume of some fuel—, for example, miles per gallon, while foodstuffs differ

enormously in the amount of energy that a given weight will supply; 100 gm. of cabbage will supply 10 Calories, 100 gm. of olive oil 900 Calories. Some foods contain much water, others little; even when this water is eliminated there may be wide differences in Calorie value; a gram of dry cane sugar will supply 4 Calories and a gram of dry butter fat 9 Calories. Because of these great differences between different foodstuffs it is essential to calculate the energy value in terms of Calories in even the most elementary estimate of food requirements and of the adequacy of diets.

The chief oxidizable components of foodstuffs are carbohydrates, fats and proteins. Carbohydrates have the general formula $C_m(H_2O)_n$. Those that human beings can use as food are 6-carbon sugars in which *m* equals 6, such as glucose (dextrose or grape sugar), fructose (laevulose), galactose, and carbohydrates with larger molecules built up of these 6-carbon sugars, including cane sugar (sucrose), milk sugar (lactose), maltose, starch and glycogen (animal starch). In digestion these larger molecules are broken down to 6-carbon sugars which are absorbed, banked in the muscles and liver as glycogen, and broken down again to glucose, which is the legal currency in further metabolic processes. Since starch forms about 70 per cent. of cereal grains, carbohydrates supply all but a small fraction of mankind with at least two-thirds of their Calories.

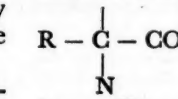
Of the substances in foods which are reckoned as 'fats' over 90 per cent. are true fat; that is, compounds of fatty acids and glycerine. They are derived not only from the fatty foods such as butter, margarine, suet and vegetable oils but also from other food in which the fat is not obvious. Proteins, which contain nitrogen, are more complex substances which will be considered in more detail later.

The simpler units into which carbohydrates, fats and proteins are split are absorbed; some items are incorporated into body structure, others are burnt at once or stored for burning later on. The Calorie value of foodstuffs can be calculated approximately by allowing 4 Calories per gm. for carbohydrates and proteins and 9 Calories per gm. for fats.[1]

[1] These figures are approximate; the heat of oxidation of a gram of glucose is 3·75 and of starch 4·22. Proteins are not completely oxidised by animals; they therefore supply animals with less energy that they evolve when fully oxidised in a bomb calorimeter. Mammals excrete most of their nitrogen as urea; birds, which excrete the less oxidised compound uric acid, get less than 4 Calories per gram of protein. In more exact studies of energy exchange the actual heats of oxidation of the foods and of the excreta are measured in a bomb calorimeter. The energy expended by an animal can be measured by putting it in a calorimeter chamber and measuring the heat, into which all energy is eventually converted, by the rise of temperature of a current of water running round the chamber. The oxygen used up, and the carbon dioxide and nitrogen excreted can be measured, and from these data three simultaneous equations can be derived which connect the amounts of protein, fat and carbohydrate oxidised. The energy expended by human beings in various activities can be estimated most conveniently by measuring the oxygen consumed. Unless the composition of the diets is abnormal the energy evolved when one litre of oxygen is used varies little from 5 Calories.

Machinery and Structure

Proteins.—Of these three chief organic components of the structure of animals and vegetables (and therefore of food) proteins occupy a unique place. Animals can make carbohydrates and fats out of proteins, fats out of carbohydrates and, possibly, carbohydrates out of fats; but they cannot make proteins out of either fats or carbohydrates and simple nitrogen compounds. The units of which proteins are built up are amino acids; with one exception, the 22 amino acids that occur in protein have the common structure



base. The amino acids are joined together in chains, with the COOH group of one amino acid linked to the N atom of the next.

Most protein molecules contain at least one molecule of each of these 22 amino acids; one protein molecule may be built up of from 140 to some 4,000 amino-acid molecules; there is, as far as we know, no restriction on the order in which these amino acids are arranged. When first recognised, some hundred years ago, the proteins were so called because they were regarded as the primary essential stuff of living matter; all later discoveries support this view.

The amino acids into which proteins are split are absorbed from the intestine; from the food point of view proteins should be regarded as mixtures of amino acids. An animal, human or other, can be fed with a mixture of amino acids, injected in a vein, as well as, and in some conditions better than, by proteins taken by the mouth. Some of these amino acids can be made from others; some, the *indispensable* amino acids, must be supplied as such. A young animal that is not supplied with these indispensable amino acids cannot grow at the normal rate; without certain of them a grown animal loses weight and may suffer some impairment of health. The distinction between indispensable and other amino acids is not absolute; a grown animal may be able to make some of the indispensable amino acids fast enough for its needs. Chicks that feather rapidly must be supplied with glycine, which is not needed

At complete rest, an adult man expends about 1,000 Calories per square metre of body surface in 24 hours. Children expend more energy per square metre and women less. Exertion increases the expenditure by amounts ranging from some 20 Calories per hour when sitting to 25 Calories per minute in the most vigorous possible exertion.

An adult man doing sedentary work requires about 2,500 Calories per day; with strenuous work the requirements rise to over double this amount.

by the slower-feathering breeds. The amino acids needed by growing rats are arginine, histidine, lysine, valine, leucine, iso-leucine, threonine, phenyl-alanine, tryptophane, methionine. Without valine rats get a peculiar disease of the nervous system ; they are abnormally sensitive to touch and their movements are unco-ordinated. Species differ somewhat in their power to synthesize the amino acids ; it is known that men lose protein from their bodies if they are not supplied with lysine, valine, leucine, iso-leucine, threonine, phenyl-alanine, tryptophane and methionine. There is evidence also of a disturbance of metabolism when no histidine is supplied.

Vitamins.—The amino acids, if not used up as fuel, are incorporated in the body structure. An animal may build them into proteins of its body, with a composition characteristic of the species, or maybe use them to form some substances that are an essential part of the body's chemical machinery, such as the creatine of muscle. There is no sharp demarcation between the indispensable amino acids and vitamins except that the amount of any vitamin needed per day is relatively small. Valine, for example, might be called a vitamin needed to ' protect ' rats against a nervous disease. The vitamins form a heterogeneous collection of compounds which animals cannot make themselves and therefore must get from their food—and use to form part of the chemical machinery of their bodies. But, whereas a man's daily quota of any amino acid is measured in grams, his quota of any vitamins is measured in milligrams.

The clearest examples of the function of vitamins are given by certain of the B-group. Two of these, riboflavin and nicotinic acid, enter into compounds which serve as hydrogen acceptors and donators in the chain of reactions by which hydrogen is transferred from glucose to cytochrome and finally to the oxygen carried by haemoglobin in the blood—in other words, they are part of the chemical machinery used in the oxidation of glucose. Vitamin B_1 (aneurin) is involved in the further metabolism of pyruvic acid, formed by oxidation of glucose ; hence the requirements of vitamin B_1 and, probably, of riboflavin and niacine are proportional to the amount of carbohydrate oxidized.

The processes in which the vitamins are used are varied. For example, vitamin A is a constituent of visual purple ; this is broken down by light, and this breakdown gives rise to a stimulus which, passing along the optic nerve to the brain, gives rise to the sensation of vision. This is not the only function of vitamin A, for in some way it influences the development of the cells that line surfaces—on the front of the eyes and down the respiratory and digestive tracts, for example. Vitamin C controls the formation of the cells and fibres that repair wounds, and vitamin D controls the deposition of calcium salts in growing bones.

Minerals.—Nitrogen, carbon and possibly sulphur are not used by the higher animals unless supplied in organic compounds. Various other elements, which enter into the structure of the bodies of animals, can be used if supplied in inorganic forms. Among these, sodium, potassium, calcium, magnesium, iron, chlorine, iodine and phosphorus appear in animal bodies in amounts that can readily be detected and measured. The functions of several of them are obvious ; calcium and phosphorus stiffen bones ; iron is a constituent of haemoglobin. But other elements, called trace elements, are needed in minute quantities for purposes that are not fully understood. This group is known to include copper, cobalt and manganese.

The word ' nutrients ' is a convenient term for the essential constituents of food—proteins, fats, carbohydrates, vitamins and minerals.

The Common Pattern of Life Processes

Dependence on external sources of essential parts of their body structure and machinery and the need for trace elements is not peculiar to the higher organisms. Among bacteria the pathogenic are usually more exacting in their requirements than the saprophytes or semi-saprophytes.[1]

The semi-saprophyte *Bacillus Coli* can synthesize its protein from ammonium salts and simple compounds of carbon, hydrogen and oxygen. But many strains of the typhoid bacillus will not grow without tryptophane and grow slowly, until adapted to the restricted food supply, if not provided with eight other amino acids. Many of the bacteria do not multiply unless supplied with the vitamins aneurin, riboflavin, niacine and pantothenic acid. Aneurin is needed by *Staphylococcus Aureus*, but is made by the diphtheria bacillus. It appears that similar structural materials and chemical machineries are common to the highest and lowest organisms ; but while some species can make the essentials for themselves, others must get them from their food.

Quality and Measurement

Proteins.—Proteins, carbohydrates and fats are measured by weight. But different proteins contain varying amounts of the indispensable and semi-indispensable amino acids. The three basic amino acids, arginine, histidine and lysine make up some 20 per cent. of the proteins of leaves and of animal cells, of milk and of eggs, but not more than 7 per cent. of the proteins of cereal seeds. A young animal, therefore, needs less of the proteins of the first group than of the cereal proteins alone in order to maintain a given rate of growth ; more of the second than of the first group is needed by a grown animal for maintenance. The rough distinction is therefore made between *first class* or *animal* protein, and *second class* or *vegetable* protein ; although the proteins of leaves should come in the first class. The proteins of legumes are regarded as intermediate between two classes. However, young rats grow as well on a mixture of equal parts of wheat protein and milk protein as on milk protein alone. There is no reason to suppose that the growth of any young animal can be accelerated or its physique improved by raising the proportion of ' first class ' protein above this level.

Units of vitamin.—When vitamins were first discovered they could be defined and recognised only in a negative way. The only possible units of measurement were the amounts that would prevent or cure a corresponding disease. The earlier estimates were made under varying conditions and the results expressed in units which were not always comparable.

[1] Pathogenic bacteria are those which cause disease ; saprophytes (e.g. fungus) live on decaying material.

Later these conditions were carefully standardised by a commission of the League of Nations and measurements, in terms of International Units (I.U.) recommended by this commission, became remarkably accurate. As the chemistry of the vitamins has been elucidated, chemical methods of estimation have supplemented the biological methods. Units of weight are replacing the international units for such vitamins as have been isolated in a pure form; Vitamin C is usually measured in terms of mgm. of ascorbic acid and vitamin B_1 in terms of aneurin. While niacine, riboflavin and pyridoxin are always measured by weights.

Classification of Foodstuffs

The word protective has been used as a general term to include the foodstuffs that supply first-class protein, vitamins and certain minerals, particularly calcium and iron. The term is misleading as it suggests that the sole function of these nutrients is to protect against some disease, rather than to form essential parts of the body structure. It is surely much more enlightening to say that iron forms part of the blood pigment haemoglobin than that foodstuffs that contain relatively large amounts of iron protect against anaemia (which may also be due to many other causes besides lack of iron).

The division into three groups, 'workers and warmer,' 'body builders' and 'protective foodstuffs' is definitely misleading. The second and third group cannot be distinguished, and all foods, other than minerals, can be used as fuel to supply heat and energy; in a healthy animal, that is not changing the weight or composition of its body, all organic foods are, in the end, burnt. Meat, which is classed as a body-builder, has even been especially recommended as a 'warmer' in cold weather. White flour, commonly classed as 'worker and warmer,' contains about 10 per cent. of protein, which can be and is used for making body protein, some calcium, and iron and some vitamins of the B group, although less than are contained in national wheatmeal or wholemeal flour. This classification has the one merit, that meat is not put in the category of 'workers'; it opposes the belief, still common, that a fully developed and trained person needs extra meat when doing hard physical work.

The Third Purpose of Food

Food has a third purpose—to contribute to the enjoyment of life. Without being elaborate or sophisticated, meals give much barely noticed pleasure; taken over the whole of life more enjoyment must come from food than from any other single source. The other functions of food cannot be divorced from this third function, as food is not well digested if it is not enjoyed. Human beings whose food is dull and unappetising tend to stimulate their palates with irritants that, in the end, damage the mucous membrane of their stomachs and still further impair their digestion.

In the past more stress was laid on digestibility than on any other aspect of food. Digestibility was a vague term that included the length of time that a food remains in the stomach, the proportions of indigestible material in a food and freedom from irritation of the stomach. Certain foods do and others do not 'agree' with certain people. This aspect of food deserves more attention from scientists than it receives at present. But most indigestion is not due, primarily, to any fault of the food itself, other than dullness and the addition of irritants; often it is secondary to some disease outside of the digestive tract.

The Growth of the Science

The earlier scientific studies of nutrition were applications of the techniques and theories of chemistry and physics to the investigation of the working of the bodies of animals; it followed on the progress of these basic sciences. When it was found that oxygen was consumed and CO_2 formed when organic substances were burnt, Lavoisier showed that oxygen is used up and CO_2 evolved by living animals; also that physical work leads to increased formation of CO_2. But the actual evaluation of the relation between food burnt, heat evolved and work done had to await the measurement of the heat equivalent of work some 50 years later. The recognition of the major organic nutrients—protein, fat and carbohydrate—followed the development of organic chemistry. After technique had improved and knowledge of the structure and properties of these compounds had grown, they were prepared in a state approaching purity; it then became possible to test whether they, with the necessary minerals, were all that were needed for a satisfactory diet and to prove the need for other organic substances which are contained in food in minute amounts; as the number of these substances grew they were given the name *vitamins*.

After it was proved that lack of vitamins caused certain diseases in animals, it was realised that some human diseases—beri-beri, scurvy and rickets—are due to the same cause. The earlier clinical studies of these diseases had proved surprisingly barren. Scurvy, for example, is an acute disease; its cure by fruit or fresh vegetables is dramatic; it is eminently suited for observation and experiment. Practically all the facts bearing on its cause and cure had been recorded at one time or another. Yet, at the beginning of this century, text-books of medicine advanced theories of the cause of the disease that were obviously incompatible with these facts. Comparison with the work on scurvy by scientifically trained workers at the Lister Institute, even before the introduction of modern, simple methods of assay of vitamin C, reflects little credit on clinicians. May we not, even now, be missing something as obvious, owing not so much to difficulties of technique as to faults in methods of thought?

The study of the metabolism of the lower organisms has contributed to the discovery of the food requirements of the higher animals. On the one side, it was found that a substance, called vitamin B_2 or G, which promoted growth of rats, was a yellow substance found in milk; on the other, Warburg investigated a similar yellow pigment which is involved in the metabolism of glucose by yeast; it turned out that the two pigments are the same substance, now known as riboflavin. Warburg found that amide of nicotinic acid is similarly involved in the metabolism of glucose and, later, Knight showed that it

promoted the growth of *Staphylococcus Aureus*. This suggested that it might be required by higher animals ; it was found that it would cure diseases of dogs and pigs produced by feeding on diets resembling those that cause human pellagra ; shortly afterwards it was shown that it cures pellagra in human beings.

Further Progress

Even if no discoveries are made in some entirely new direction, a large area remains to be explored and mapped. Progress is limited only by the number of workers and size of endowments. New factors needed by animals are still being discovered. The standard method used is to feed an animal on a diet composed wholly of the known factors ; this is now possible, as these factors can now be prepared pure. If the animal develops some disease it is inferred that some other factor also must be needed by this species ; it becomes ' factor X.' The next stage is to isolate it from foodstuffs that are found to prevent the disease ; to study its structure and properties ; to measure its distribution in foodstuffs ; to investigate the part that it plays in the chemical machinery ; finally, to estimate its importance to human welfare.

In this way the indispensable amino acid threonine was discovered. Up to 1936 this amino acid had been missed in all analyses of proteins. Professor Rose fed young rats on mixtures of all known amino acids, together with the necessary vitamins and minerals and non-protein food to supply energy. The rats did not grow, although they would grow at the normal rate if the mixture of amino acids was replaced by pure protein or a mixture of amino acids prepared by digesting protein. Professor Rose inferred that proteins must contain some unknown constituent and further search led to the discovery of threonine.

It is this discovery of some new ' factor X ' and its subsequent identification that has led to the curious expansions and contractions of the vitamin alphabet. Vitamin B_2 (or G) has become riboflavin, vitamin B_3 pyrodoxin, vitamin M pantothenic acid. Some of these newer factors were missed in the earlier investigation on account of their wide distribution in foodstuffs or their association with the factors first identified.

Little attention has been paid, as yet, to them in consideration of human nutrition. Any lack of them is liable to be overshadowed by a simultaneous and greater lack of one of the better known vitamins. It is highly probable that other such accessory factors remain to be discovered.

Much more remains to be found out about the modes of action of nutrients. We do not yet know the whole story of the metabolism of amino acids ; are they used only to make compounds such as creatine which is part of the chemical machinery of muscles and to repair damage ? or is active life dependent on a continual interchange of amino acids between cell protein and food ? Much tedious work remains to be done on the amounts of vitamins contained in foodstuffs and on the effects of cooking and processing. We need to learn more about the storage, action and rate of loss of vitamins from the body. The study has recently been complicated by the discovery that a considerable fraction of our supply of vitamin B_1 and niacine may be formed by bacteria in our intestines. Food may affect our supply of these vitamins, not only by the amounts that it contains, but also by its influence on the synthesis by these bacteria.

The Intermediate Zone

In most of the earlier experiments on the effects of defective food, some constituent was omitted as completely as possible ; but later, the question was asked, what happens if the supply is reduced to a less degree and what happens if it is raised above the usual level ? The answer was, that there is a wide intermediate zone between the level at which specific evidence of disease appears and the level at which an animal's health, growth and vigour are at a maximum. This zone has been studied in most detail in experiments on the effect of varied intakes of ascorbic acid on guinea-pigs. If a guinea-pig is allowed 0·5 mgm. of ascorbic acid per day it will not develop scurvy ; it will not lose weight, though its fur may have become less sleek. But, if a cut is made through its skin, healing is delayed since the cells and fibres, which should unite the sides of the wound, do not develop properly ; if a bone is broken, the callus which should join the fragments, does not form. With higher daily doses healing improves ; the firm and rapid healing or union of bone at least 2 mgm. (four times the amount that will prevent scurvy) is needed. There is no further improvement with doses above this level.

Rats were fed on a diet similar to that of the poorer classes in Aberdeen. In each generation their rate of growth and final weights were less than those of rats on the usual laboratory diet. They tended to die out, as their litters were small and many young died before weaning, particularly in the third generation. Other rats grew and bred normally when fed on this same diet with calcium salts added ; so, the chief fault of the diet, as a food for rats, seems to have been that it supplied too little calcium. Similarly, rats grew slowly and reared few young when fed on diets which, in respect of the amounts of the B group of vitamins, resembled the diets of English people who use white flour. On the other hand, the growth of rats is improved by increasing the amounts of vitamin A in their food up to five times the amount that will prevent any obvious sign of disease ; growth and length of life are increased by increasing the supply of riboflavin above that in the ordinary diet.

Experiments on Human Beings

Although a common pattern of structure and working runs through the whole range of animal life, species differ, in detail, in their ability to make the essentials of their bodies' chemical machinery and in their response to deficiencies. Guinea-pigs, monkeys, apes and men, unlike other animals, cannot synthesize the ascorbic acid that they need. Young rats grow much more rapidly than children. Children do not need such a high ratio of calcium (for bone formation) to Calories (for maintenance) as young rats need. We need not, therefore, assume that the diet of the poorer classes in Aberdeen was as disastrous for Aberdonians as it was for rats, unsatisfactory

though it may have been. On the other hand, human beings are much more susceptible than the lower animals to injury to the higher levels of the nervous system. Quantitative and detailed information about the effects of food deficiencies on human beings can be got only from studies on human beings.

Our knowledge of the effects of food deficiencies on men came, primarily, from unpremeditated and unplanned experiments, due to privation or errors in choice of food. In such experiments several nutrients may be deficient at the same time and the subjects may suffer from cold, overwork, injuries and infections. A few deliberate experiments have been made in which a single nutrient or a known group of nutrients has been excluded from the diet of human subjects while the environment has been maintained at a customary or an optimum level. One interesting result of such experiments has been that swelling and bleeding gums, characteristic of the scurvy of unplanned experiments, may not be seen even after six months on a diet containing no ascorbic acid, when the subject is extremely weak. The first result of such a diet is weakness and fatigue; healing of wounds may appear to be normal, even after three months on such a diet, but after six months is very defective. Night blindness and skin changes occur only after many months on a diet containing practically no vitamin A.

The Intermediate Zone in Human Nutrition

In the unpremeditated experiments the relation between disease and diet has rarely been recognised with certainty, even when the defect and its consequences have been gross, until it has been indicated by experiments on other animals. It is far more difficult to establish that less severe faults of the food may produce minor degrees of damage or disability comparable to the intermediate states seen in experiments on animals. For these experiments are made on standard animals, living under standard conditions; one factor at a time can be varied and any minor changes in health, in rate of growth, in length of life or activity can be attributed to this variation. But human beings vary widely between themselves and live under the influence of a welter of variable factors; the effect of less extreme defects of the food on physical welfare must be disentangled from the effects of these other variables by deliberate controlled experiments. One of the most remarkable conclusions from such experiments has been that states similar to those commonly called neurasthenia, loss of initiative, irritability, apathy, may be produced in a matter of two or three months by a diet which supplies little less vitamin B_1 than is found in an ordinary diet in which the bread is made from white flour. However, the effects of deficiency may vary considerably with individual susceptibility.

Valuable as these experiments are, the results cannot be applied without qualification to malnutrition as it is commonly seen. In the first place, the experiments last for a comparatively short time only; none has been made on children, who are more likely than adults to be more severely and rapidly affected by deficiencies.

In the second place, in the outside world, under the influence of many adverse factors, signs of deficiency may appear sooner than in these tidy experiments, their order of appearance may be different and their character changed. In particular, the experiments can give little indication of any lowering of resistance to such diseases as tuberculosis, which is generally accepted as one of the most serious dangers of malnutrition when the environment is unfavourable.

Experiments have also been made in which the change has been in the opposite direction—the diet has been improved. Prompt and obvious consequences of such a change are most likely during periods of growth; mothers and their babies may be affected during pregnancy and lactation, and children until they are fully grown. In the best known experiment, begun in 1921, a group of boys in a village settlement, in which the ordinary diet was originally chosen with every regard for the welfare of the boys but was poor according to modern standards, were given an extra pint of milk per day in addition to the ordinary allowance of $\frac{1}{8}$ to $\frac{1}{4}$ pint. The experiment was continued on some of the boys for three years. This group grew considerably faster than other boys living under similar conditions and eating the same food, except for the pint of milk; they were more lively and their general health was better. Such experiments are most satisfactory when made in an institution in which the diet can be strictly controlled; in later experiments, made in 1926 and 1936–37 large numbers of children, living at home, were given extra milk at school. It is highly probable that many of the children who got this extra milk were given less at home in consequence. This may, in part, explain why the difference between the growth rates of the 'extra milk' children and those of the controls was less in the 1926 experiment than in that of 1921. By 1936 these earlier experiments had borne fruit; more milk was being drunk by children throughout the country and the difference between the 'extra milk' children and the controls was less.

A few experiments have been made in which the diets of pregnant women have been improved and the effect on the health of the women and their babies has been studied. In all there has been some evidence of benefit; in the most detailed experiment, made in Toronto, a group of women was supplied with food sufficient to raise their diet to a high standard. This group was compared with a similar group that received no food supplements. The general health of the mothers, who had the extra food, and of their babies was improved and the number of babies that were being breast fed six weeks after birth was increased.

The remarkable improvements in health and vitality, that an extra supply of some vitamins gave to rats, raised the hopes that human beings might derive similar benefits from extra vitamin, or (on the theory that it is no use to strengthen only one link of a chain) with a mixture of several vitamins. It has been claimed that doses of vitamin A will reduce the incidence or severity of colds and that vitamin C reduces fatigue and the incidence of rheumatic fever and respiratory infections. On the whole, the better controlled these experiments have been the less has been the evidence of any benefit.

These experiments on human beings are no light undertaking. If the results are to be significant :

(1) The sample of the population studied must be large enough. For example, the maternal mortality rate is about 3 per 1,000 births ; if it is used as a criterion, the sample studied should run into several thousands.

(2) In order to rule out variations due to other factors, such, for example, as the introduction of sulphonamide drugs during recent years, a control sample must be studied at the same time. This sample must be comparable to the sample subjected to the experiment ; for example, a sample of pregnant women drawn from those attending antenatal clinics should not be compared with the general population of pregnant women.

(3) The actual food eaten by the subjects should be recorded ; otherwise a small proportion who are benefited, because their diet is defective in the nutrients considered, may be swamped by the remainder. The sample should be broken down according to the quality of the diet.

(4) The experiment should be carried on for a time which is more than a trivial fraction of the lifetime of man.

Malnutrition

Two types of malnutrition

When we turn from nutrients to actual foodstuffs, we find that Calories can be supplied by any foodstuff ; vitamin D, proteins that contain a high proportion of the indispensable amino acids, and calcium are derived mainly from animal products—milk, eggs, meat and fish ; vitamin A and its precursor, carotene,[1] come from milk, eggs, green vegetables and yellow roots ; vitamin C from fresh fruits and vegetables. Milk is especially rich in riboflavin and meat in niacine ; there are large amounts of the vitamins of the B group, particularly of aneurin, in the germs and outer covers of grains.

Now animals use up food to maintain their own existence ; any food that they may provide for man is only a by-product. Hence an acre of land used to produce cereals which are eaten, as such, by human beings will yield from four to ten or more times as many Calories for human consumption as will one acre used to feed animals, whose milk, eggs or flesh are eaten by mankind. From the point of view of the producer, animal products need more land ; from the point of view of the purchaser, animal products are expensive. Green vegetables and fruits may also give a poor Calorie yield per acre and are not easily transported and stored ; in colder climates they cannot be grown in winter. They also are expensive. Hence peasants with little or unfertile land and non-producers with low incomes are likely to get too little of the indispensable amino acids, of vitamins A, C and D and of calcium, and are liable to suffer from the corresponding deficiency diseases.

When rice is polished or white flour milled the germ and outer cover of the grain are removed and, with them, the greater part of the aneurin and other vitamins of the B group. Where polished rice or white flour make up a large part of the diet there is a risk of gross deficiency, particularly of aneurin, but also of riboflavin and niacine. When the cereal eaten is maize, there is a greater risk of niacine deficiency. In Great Britain cereals supply only 30 or 40 per cent. of the Calories and other foodstuffs supply vitamins of the B group ; the risk of deficiency of these vitamins is less serious.

If the diets supply enough Calories and enough of the five nutrients, vitamins A, C and D, first-class protein and calcium, there is little risk of deficiency of any other nutrients, unless the cereals eaten are rice, white flour or maize ; and the risk of deficiencies due to eating these debased or inferior cereals is less if the supply of the first five nutrients is sufficient. There are, therefore, two broad types of malnutrition ; on the one hand, that due to insufficient food of any kind or of animal products (milk especially), fruits and vegetables, which occur among the poor generally; and, on the other hand, the type associated with the cereals, polished rice, white flour and maize. The second type is almost always associated with some degree of the first. Both are diseases of poverty.

Peasant Poverty

We people of the wealthier countries are apt to forget that our way of life is exceptional. Over half the population of the world are peasants living near the edge of famine ; that is, they may not get even enough Calories. Among the 388 millions of India, according to a report made by the Director General of the India Medical Service in 1933, the population is excessive in relation to the food supply in 40 per cent. of the villages ; periods of famine or scarcity of food occurred in one village out of every five during the period of ten years in which there was no exceptional failure of rain. The scarcity of vitamin A in India is shown by the occurrence of ulceration of the front surface of the eyeball (keratomalacia). The eye may be destroyed, or, if the ulcer heals, an opaque scar is left which causes more or less complete blindness. This is said to be the commonest cause of blindness in India, where, according to the report quoted, there were 2½ million blind. Three and two-thirds millions were night blind, owing to lack of vitamin A. Since sunshine will take the place of vitamin D, rickets and osteomalacia may be rare in India, even when the diet is very poor ; but in some villages in the foothills of the Himalayas, symptoms of osteomalacia are found in nearly every household. The poor physique of many Indians may be due, in part, to insufficient first-class protein ; but since growth can be accelerated by supplements of calcium lactate, the chief factor limiting growth seems to be calcium.

With this poverty goes the cereal disease of rice-eating people—beri-beri. The number of cases under treatment in India in 1931 was estimated at 16,966. In Japan in 1928 the death-rate from beri-beri was 0·178 per thousand ; that is about one-third of the death-rate from tuberculosis in New Zealand, although far lower than the tuberculosis death-rate in Japan. In Manila, as recently as 1929, out of every 1,000 babies born alive, the number that died of beri-beri alone was nearly equal to the number per 1,000 that died

[1] See Appendix.

in New Zealand from all causes. These cereal diseases are not confined to the older civilisations. beri-beri is common in Newfoundland and Labrador, where people live for many months of winter largely on white flour, with little meat or vegetables. In the southern states of the U.S.A. pellagra became common in the early years of this century and was the chief cause of death in the late 1920s.

Evidence of lack of riboflavin in India is given by the frequency of the specific signs (sore lips and cracks at the corners of the mouth) and by a form of dimness of vision, which is thought to be due to this cause. Scurvy, due to lack of vitamin C, is prevalent in Africa ; it has been described as one of the factors limiting the employment of natives in the Union of South Africa and reported to affect 60 per cent. of native labourers in Rhodesia.

Even when the diet is seriously defective the gross deficiency diseases attack only the more susceptible of the people. During the siege of Madrid the rations, from the autumn of 1937 to the spring of 1939, supplied only about 1,000 Calories per head per day. But the number of persons with any particular type of deficiency disease treated in hospital amounted to only about one per thousand of the population. Women were more subject than men to symptoms of aneurin deficiency, but more men than women got a type of loss of visual acuity, usually attributed to lack of riboflavin or another member of the B group. The scarcity of any nutrient or group of nutrients picks out only the more susceptible or waits until some extra strain is imposed. Famine oedema, the sign that the starved body has reached its limit, was not common until the cold of the winter of 1938–1939 was added to two years of scarcity of food ; Madrid surrendered in March 1939. During pregnancy extra calcium is needed for the baby's bones ; consequently osteomalacia most commonly begins during pregnancy. Pregnancy makes other and less obvious demands ; Nixon reports that pregnant women among the poor Chinese population of Hong Kong may show increasing signs of beri-beri with each month of pregnancy. During the last war pregnant women were the first to suffer from night blindness due to lack of vitamin A.

The effects of semi-starvation in Madrid were not confined to the limited number who broke down completely and were treated in hospital. Many more suffered from loss of memory and of power of concentration, changes of character, irritability, anxiety, insomnia, weakness and fatigue. These troubles are real enough and serious enough ; they are common enough in all countries. But it is almost impossible to measure them, to correlate them with the quality of the diet and to decide how far they are due to faults of nutrition and how far to other causes. Although such troubles may well be the most common ill effects of malnutrition in the better-fed countries, attention must be focussed on other defects that can be expressed in figures.

Anaemia

There is one defect, almost certainly evidence of malnutrition, which can be detected and measured with precision ; this is a type of anaemia which is commonly attributed to lack of iron and is cured by large doses of iron. The haemoglobin, the red pigment of the blood which contains iron, is reduced and the amount can easily be measured. Whether or not the reduction is due to an actual shortage of iron in the food may be questioned, but it is undoubtedly due to some faults in the diet. This anaemia is common among women. One of the earliest students of its frequency in Britain gave this estimate of the seriousness of this minor defect : ' It is true that most women investigated complained of few, if any, symptoms of ill health ; but this was due to the fact that they had been accustomed to live subnormal lives for years and had really forgotten the joy of good health. They invariably admitted that this was so, when after efficient treatment, their blood had been restored to normal.' Women are particularly liable to anaemia during pregnancy. In an investigation in England and Wales the average haemoglobin in the blood of pregnant women in families with an income under 6*s.* per head per week, eating an average of 28 gm. of first-class protein per day, was 76 per cent. of normal ; among these families with family incomes of over 25*s.* per head, eating 55 gm. of first-class protein per day, the average was 90 per cent. This anaemia may persist for years after the baby is born. It is an obvious result of the supply by the mother to the baby, both before and after birth, of food which the mother's diet does not replace. In the Toronto experiment (p.164), more of the well fed than of the badly fed mothers were nursing their babies at six weeks after confinement. Seeing that a mother's milk often contains more of vitamins A and C than she gets in her food, it is highly probable that many failures or inadequacies of breast feeding are due to undernutrition. It may be argued that women in less well fed and less sophisticated countries commonly suckle their babies ; but, also, a high proportion of these babies die.

Children also suffer from anaemia and this anaemia has a class distribution. In 1942 nearly 2 out of every 5 children aged 5 to 11 years, attending two municipal elementary schools in Edinburgh, were anaemic, but only 1 in 20 of the children attending private schools.

Vital Statistics

Wide differences in health between better and worse fed countries are shown in vital statistics, thus :

DEATH RATES PER 1,000 AT EACH AGE PERIOD

	Under 1 year Infant Mortality Rate 1937	1 to 4 years, 1937		Tuberculosis, all ages, 1936	
		Males	Females	Respiratory	Other
New Zealand, Europeans	31	3·0	3·0	0·36	0·09
Netherlands	38			0·36	0·14
U.S.A.	54			0·51	0·05
England and Wales	59	5·4	4·8	0·53	0·11
Italy	109	14·9	14·5	0·65	0·22
Japan	106			1·41	0·50
Rumania	118			1·45	0·31

Differences between classes among the better fed people are equally striking :

ENGLAND AND WALES, 1930–32

	Infant Mortality Rate	Tuberculosis (Respiratory) Death Rate, Men 20 to 65 years. As per cent. of Class I
Class I. Professional	33	100
,, II. Intermediate between I and III.	45	120
,, III. Skilled workers	58	190
,, IV. Intermediate between III and V	67	204
,, V. Unskilled workers	77	273

These deaths of babies and young children and deaths due to tuberculosis are outstanding examples of deaths which might be prevented by a better standard of living. If these rates in England and Wales fell to the level of New Zealand the lives of about 12,000 babies that die in their first year and 6,500 persons that die of tuberculosis would be saved each year. A considerable proportion of the deaths of babies are due to prematurity. In Glasgow it was recently found that the average diets of mothers of premature babies and of still-born babies supplied only two-thirds of the animal protein and calcium supplied by the diets of the mothers of live-born full time babies. In the experiment in Toronto, 2 per cent. of the babies of mothers who received extra food and 8 per cent. of the babies in the control group were born prematurely. Three per cent. of the babies of the second group died, but none of the babies of the well fed mothers.

The anaemia which is common among pregnant women contributes to the infant mortality. The babies of anaemic women are liable to anaemia too, and anaemic babies are twice as likely as others to die in their first year.

Many people who develop tuberculosis had an especially poor diet before any evidence of the disease appeared. The most convincing evidence of the connection between tuberculosis and food was the rise in the incidence of tuberculosis among children in belligerent countries and among the general population in neutral countries during the last war ; the death-rates in these two groups were not affected by war work, which contributed to the high death-rates among adults of the belligerent countries. In Denmark the tuberculosis death-rate in 1917 was 28 per cent. above that in 1914 ; but in 1918, when dairy products were no longer exported to Germany, but were rationed generously among the Danes, the rate fell to the pre-war level.

Changes since 1900

Experiments have shown the close relation between the rate of growth of children and food. This change has run parallel to an improvement of children's diets ; the amount of liquid milk consumed in Britain rose by 18 per cent. between 1933 and 1939 ; and the number of children taking milk in schools from 20 per cent. in 1934 to 66 per cent. in 1939. During recent years the gap between the statures of well-to-do and poor children has shrunk. But there is still a gap ; even in 1943, boys, at all ages from 5 to 10 years, from a comparatively well-to-do district in Cambridge were about one inch taller and two pounds heavier than boys from a fairly poor district.

Fifty years ago there was abundant evidence of malnutrition in every street in the shape of bow legs due to rickets. Although rickets, severe enough to cause deformity, is becoming rare in Britain, the few cases that still occur warn us of the danger of any relaxation of our food standards. In Germany rickets became considerably more common during the years immediately before the war.

Nutrition and Size of Family

With a fixed income the amount of money per head available for food must fall if a family grows ; as a result, it has commonly been found that the amount of milk consumed per head falls, instead of rising, with the number of children. Nutrition suffers ; in a school in one of the poorer areas of Cambridge there was a difference of ¾ in. and 3 lb. between the average heights and weights of children of families with one or two children and of families with three or more children. In a better-off area the difference between the children of the larger and smaller families was less.

Dental Caries

In spite of better choice of food and all the science of nutrition, people in the more highly civilised countries suffer far worse than others from decayed teeth. If this is, as is commonly supposed, due in some way to our food, it is a sign of malnutrition, however good our food may be in other ways. But we are still uncertain of the nature of the fault in our diet. There are three main theories. According to the first, teeth become more liable to decay owing to lack of vitamin D both before birth and during early childhood. But rickety children, born of mothers with osteomalacia, may grow up without any signs of decay of teeth ; while children without any sign of rickets, born of well fed mothers, may have decayed teeth ; the lack of vitamin D must, at most, be no more than one of the factors contributory to decay. The second theory blames the softness of civilized food, postulating that the teeth do not develop properly because they are too little used. There is no doubt that the jaws of civilized people are underdeveloped, but there is no indication of the way in which the teeth are thereby rendered more liable to decay. According to the third theory, sugar is fermented on the teeth by bacteria and forms acids which dissolve the teeth. Decay of teeth is most common among peoples who eat large amounts of sugar ; during the war, with sugar consumption cut down by two-thirds and sweets rationed at 3 oz. per week, there has been a distinct improvement in children's teeth. But this is not the whole story ; for, among the English middle class, those who were born in the second half of last century have the very worst of teeth ; but they ate far less sugar and sweets than did later generations and many of

them had plenty of milk, butter and eggs to supply vitamin D and calcium. The outstanding fault of middle-class diets of that time was lack of vitamin C, as vegetables were over-cooked and little fruit eaten. In view of the relation of vitamin C to the formation of teeth in guinea-pigs, it is possible that lack of vitamin C may have helped to make the world's worst teeth. There is evidence that the presence of a moderately high concentration of fluorine (about 1 p.p.m.) in drinking water protects the teeth ; it is suggested that fluorides in the teeth may inhibit fermentation of sugars by bacteria ; but this, again, cannot be the only factor.

Decay of teeth causes so much discomfort and pain to so many people and is at the root of so much other illness that it cannot be regarded as a minor effect of malnutrition. The science of nutrition would do a great service to better nourished people by teaching us how to keep our teeth sound.

Surveys of Diet and Health

Even in countries in which gross deficiency diseases, such as beri-beri and pellagra, are frequent, the majority of the people do not suffer from it. The diets of the greater part of mankind contain enough of all nutrients to prevent gross disease, except among the more susceptible, but not enough for optimum development and health. It is the intermediate zone and the disabilities, less obviously due to malnutrition, that are of first importance in shaping social policy. The few deliberate experiments on mankind give an indication of the types of impairment of health and efficiency that may be found, but give no measure of the degree and severity of the disabilities that actually occur, among people of varying susceptibility, when factors of the environment may be unfavourable. They can be learnt only by actual studies of the relation between food and development, health and efficiency.

Food Consumption

First, quantitative information about food consumption is needed. This may be obtained in three ways.

(1) The total food supply of a country may be calculated from estimates of the food produced, imported and exported.

(2) The food consumed by each of a group of families may be measured. Either (A, the budget method) the housewife keeps records of all the food that enters the house over an agreed period, or (B, the weighing method) all food in the house at the beginning of a period, all food brought into the house during the period, all waste and all food remaining in the house at the end of the period are weighed by a trained investigator.

(3) Individuals may keep a record of the actual food that they eat ; the food may be measured by weighing or by some simpler method.

From the estimate of foodstuffs consumed the Calories and nutrients consumed are calculated with the help of tables of composition of foodstuffs or, occasionally, by actual analysis.

The chief value of method (1) is that it gives an estimate of increase of the total supplies of a country that would be needed in order to meet any standard. It gives the average consumption per head without any indication of the actual consumption by families and individuals, since distribution is unequal. Method 2 (A) is fairly accurate, particularly when the housewife is accustomed to keep accounts ; waste must be guessed. In method 2 (B) the apparent greater accuracy of measurements is outweighed by the disturbance of the current of family life. In method (3) made-up dishes are weighed ; the composition of these may differ widely from the composition given in tables owing to differences of recipes and methods of cooking. In methods (2) and (3) the families or individuals who are willing to co-operate are not, strictly, a fair sample of the population. Owing to the variable composition of foodstuffs (as, for example, the ratio of fat to lean in meat) the amounts of nutrients calculated from the tables of the components of foodstuffs may differ from the amounts found by actual analysis by 10 or 20 per cent. These surveys, therefore, give no more than approximate estimates of the food or nutrients consumed ; they should be checked one against the other.

Family Coefficients.—Women and children may need fewer Calories and more of certain nutrients than do adult men. In comparison of the food of one family with that of another or with any standard of requirement, allowance must be made for these differences. A series of coefficients has been worked out, which express the number of Calories required by a child of any age as a decimal of the requirements of a hypothetical adult man. Using such coefficients, the 'man value' of a family of one man, one woman (coefficient 0·83), one child of 9 years (coefficient 0·7) and one child of 5 (coefficient 0·5) is 3·03. Different coefficients should be used for each nutrient ; growing children need more protein and calcium, relatively or absolutely, than do adults. In this way the consumption of nutrients per 'man value' in families can be calculated and the diets of different families or groups of families can be compared.

More commonly than not, the actual distribution of a family's food does not conform to these coefficients ; father usually gets more than his share of protein, if not of Calories. The distribution among individuals can be obtained only by measuring the food actually eaten by individuals ; this is a tedious business and such surveys cannot be made on a large scale.

These measurements of food consumption may be supplemented by the use of tests that reflect the amount of some nutrient in the diet. For example, the concentration of ascorbic acid in the blood, which can be measured, runs roughly parallel to the amount in the diet. Most such tests are in the experimental stage. As our knowledge of the functions of various nutrients grows, better tests will be devised and should help in this study of the relation of health to diet.

Measurement of Health

Having estimated food consumed, we need measures of health, development and efficiency. We can take, as criteria, vital statistics, particularly tuberculosis death-rates and infant mortality rates, or heights and weights of children, as these can be expressed in figures and a large volume of fairly accurate data are available. Comparisons may be made between countries,

between different periods in a single country or between different classes in the same country.

Food is not the only factor that causes these differences. Overcrowding, which often goes with bad food, increases the risk of tuberculosis and of other infections which endanger the lives of babies and retard their growth. More definite evidence of malnutrition may be obtained by examination for certain signs which are regarded as specific evidence of deficiency of certain nutrients; for example, the sore lips and cracks at the corners of the mouth characteristic of riboflavin deficiency. The most satisfactory information on the relation of disabilities to the minor degrees of malnutrition is obtained by the combination of an extensive survey of food consumption with an intensive study of the diet and general health and efficiency of smaller groups. These studies may include a variety of physical measurements such as chest circumference, vital capacity, test of strength, endurance or co-ordination.

Valuable information may be obtained from studies on populations whose diets are relatively uniform. The average haemoglobin in the blood of women in the W.A.A.F. rises by about 8 per cent. during the first 6 months after recruitment, to a level above that usual for women. This rise may be due to several factors, including improvement in their diet; but it is satisfactory evidence that the W.A.A.F. diet supplies at least enough of iron and other factors that are needed to maintain the level of haemoglobin in the blood. Signs of riboflavin deficiency have not been found in the R.A.F.; the average amount of riboflavin in their food—about 1·9 mgm. per day is therefore enough to prevent overt evidence of deficiency. On the other hand, these signs became common in labour companies in Africa, when they had under 1 mgm. per day.

There is still much to be learnt about the relation between diet and health, growth and efficiency. Unfortunately, human individuality is not shown only in the response to variation in the diet. One investigator uses one method, another uses another; they may express their results in terms which are not comparable. We need a combined attack with uniform methods, that will provide good statistics on which more precise conclusions can be based.

Standards of Food Requirements

Any plans for improvement of nutrition must be based on specifications of the amounts of food required. In calculation of food requirements it has been assumed, as working hypotheses, (*a*) that it is possible to estimate the requirements of Calories and of each nutrient independently, and (*b*) that the amounts of these nutrients needed is not affected by the type of the foodstuff in which they are supplied. These hypotheses are not strictly true; it has been necessary to modify them in the case of vitamin B_1 and, in the latest standards, the requirements of riboflavin and niacine, also, are assumed to vary with the Calories used. It may be found that the influence of different types of foodstuffs on the bacteria in the intestine may influence the amounts of nutrients that must be supplied by the food, quite apart from the amounts which these foodstuffs themselves contribute.

Standards of food requirements may be used either to assess the quality of diets that people eat, or to set up a goal which it is proposed to reach. Since there is an intermediate zone and since it is not possible to reach the optimum level at once, we must have different standards. It would be useless, for the present, to judge the diet of Indian peasants by an optimum standard or to attempt to conform the food supply of Britain during the war to this standard. We can consider three standards (1) the minimum which will prevent gross diseases, such as beri-beri, (2) the optimum, such that no improvement of any kind could be obtained by further improvements of the diet, (3) a standard intermediate between the optimum and minimum.

Standard (1) is based, in some cases, on the relation between the evidence of deficiency disease and the supply of certain nutrients. For example, beri-beri is rare when the diet supplies over 0·1 I.U. of aneurin per Calorie. In other cases, experiments have determined the level of intake that will prevent or cure the earliest signs of lack of any nutrients; such as the amount of vitamin A that will restore impaired dark adaptation to normal.

No harm can be done by any surplus, within reason, of most nutrients. Eskimos enjoy good health on diets which are made up almost entirely of meat, and therefore contain an exceptionally large proportion of proteins. The amount of vitamins that will cause any ill effects far exceeds the amounts that will be found in a day's supply of any ordinary foods. A rat can be poisoned by large doses of vitamin A; but the daily amount needed to do so would, if given in divided doses, keep a rat in health for some hundreds of years. Optimum standards can, therefore, as a rule, afford to be so generous as to rule out any possibility of deficiency, without any fear of excess. In some instances it is possible to put a fairly precise upper limit to requirements. If a man takes more than 70 mgm. of ascorbic acid per day he excretes a large proportion unchanged; his body becomes saturated and it is improbable that he will gain anything from larger intakes. In other instances, that of vitamin A for example, without evidence of such saturation level, experiments on animals indicate the amount by which the optimum should exceed the minimum.

The number of Calories should be limited; if a fully developed person takes more than he expends as heat and work he grows fat and possibly upsets his digestion. But, since Calories are cheap, individual requirements can usually be left to the individual; estimates are needed only in planning food supplies.

An optimum standard must take into account the third purpose of food, that is, to give enjoyment. It might be possible to put up a synthetic diet that would supply abundant Calories and all the possible nutrients, but it would be wholly unattractive. Any standard that sacrifices this essential function for any reason of convenience or expediency, is not an optimum and may be intolerable as a minimum.

In selecting an intermediate standard it is difficult to decide the point in the intermediate zone at which to stop, and many other factors besides actual food value must be taken into

account. During the war munitions have competed with food for shipping and a compromise has been sought between the rival claims of different nutrients, of habit and of taste. When such compromises must be made the needs of growing children and of pregnant and nursing women, who are most likely to suffer from any deficiency, should come first.

The optimum standard most commonly used at present is that proposed by the National Research Council of the U.S.A.

Planning

The key words of the section *Malnutrition* were : 'They had been accustomed to live subnormal lives for years and had forgotten the joy of good health.'

The major diseases—beri-beri and pellagra, scurvy and rickets—are serious enough ; with the diseases, such as tuberculosis, to which malnutrition lays mankind open, they must account for millions of lives per year. But the greater evil is the subnormality that robs life of much of the capacity for work and enjoyment.

More and Better Food

Better nutrition involves more Calories, and much more first-class proteins, vitamins A, C and D and calcium ; with these assured we would not need to trouble about other nutrients. In terms of foodstuffs we want more animal products (milk especially), more vegetables and fruits and cereals enough to ensure sufficient Calories for all. Since animals give, at most, a 10 per cent. return, in the shape of food for mankind, for the fodder that they eat, this implies a very large increase in the amount of food obtained from the soil. During the war we have seen that it has been possible, in spite of the deviation of a large fraction of our resources to war purposes, to increase the amount of food produced and consumed in the U.S.A., Canada and the United Kingdom. The reduction in consumption of some items, such as butter, has been due to exclusion of certain external areas (the Low and Baltic countries) from which supplies were obtained. It should be possible, when the dislocations of war are over, to improve the food supply not in these three countries, but also throughout the world.

Peasant Areas

Since the peoples of the more advanced countries, the British in particular, have come to depend on other countries, either for part of their food or for feeding-stuffs and fertilizers, it is reasonable to consider the problem of food supply as one involving all the world. This was done at the World Conference on Food and Agriculture, held at Hot Springs in April and May 1943. Looking at the whole world, the outstanding fact is that over one-half of mankind are peasants producing mainly for themselves and the great mass of malnutrition is among these peasants. Their farms are small, often divided into minute and scattered fields ; their implements and methods of cultivation are primitive, they use little manure and no fertilizers ; their irrigation and water conservation, if any, are inefficient. In order to get enough Calories they use their land mainly for growing cereals ; their own health suffers from lack of animal products and vegetables ; their land from want of manure and rotation of crops.

To raise the yields from these farms and to improve the nutrition of the peasants the whole system of farming must be reorganised. Much might be done by setting up farmers' co-operatives which could re-partition land, purchase agricultural implements and fertilizers and organise small scale irrigation comparable to that of Chinese villages. A change from predominantly cereal to mixed farming would, in the end, raise the fertility of the soil so much that the total yield of Calories would not fall. It is claimed that, in India, by devoting one-third of a farm, in rotation, to fodder crops for milch cows and using the manure on the land, more wheat, cotton and sugar-cane can be obtained from the remaining two-thirds than from the whole farm previously, in addition to the milk.

Apart from the improvement of methods in this vast area of peasant cultivation, yields could be raised in the more developed countries and new areas could be opened up. One-third of the cultivated area of the world has been severely damaged by land erosion ; much of this land might be restored by methods now in use.

Perishable food should be produced locally ; if food is imported the imports should be, as far as possible, compact and portable food stuffs such as grain and sugar. Agricultural and nutritional policy must take into account soil, climate and habits and temperament of the people. Milk puts the backbone into the nutrition programmes of Britain, the U.S.A. and Canada ; this is a sound policy, as a pint of milk will supply a large proportion of the day's quota of the five essentials—first-class protein, vitamin A and D and calcium, together with ¼ of the riboflavin needed ; and cows give a better all-round return for the feeding-stuffs that they eat than any other animals. But some areas are not fit for milk production, and it would be many years before the world's cows could supply a pint per head per day throughout the world. Some food or combination of foods that will take the place of milk is needed.

The Problem in Britain

A high proportion of dairy products, meat, fruit and vegetables—the foodstuffs that are scarce in the world as a whole—Britain imported from abroad ; yet in every item except meat our level of consumption was below an optimum standard. If the recommendations of the Hot Springs Conference are accepted, Britain cannot expect to draw so heavily on these scarce foods in the future. If the recommendations are not accepted we are faced with the loss of our foreign investments ; we can no longer pay for imports with interest and dividends and must cut down the imports of food. In either case we shall have to produce as much as possible of these foodstuffs at home. Milk, again, must be the key foodstuff, both because milch cows give the highest return for the food that they eat, in the form of valuable nutrients, and because fresh milk cannot be imported.

To reach the standard of 1 pint per day we should have to double our output ; this would need more cows, although the output could be

raised considerably by breeding cows that give a better yield and by eliminating diseases. An allowance of about two-thirds as much meat as we ate before the war—about half way between our peace-time and war-time consumption—would be satisfactory. If we raise the number of milch cows we cannot cut down our home production of beef and veal below a certain level, as bull calves will be born and, as it is, nearly one-third of our present beef output is cow beef. We might, therefore, reduce the most expensive of our food imports considerably.

We could grow all our vegetables and about half our fruit; we could grow and preserve more of the berry fruits, though we should still need to import more citrus fruits than before the war. The optimum standard of butter is very high; half as much again as we ate in peace time. The milk equivalent of the butter that we imported was 2,500 million gallons per year; this is about twice the home milk output. We cannot expect to reach this optimum standard until the world's supply of milk is much higher and will be fortunate (or, perhaps, in the eyes of the rest of the world, greedy) if we go back to our pre-war level.

The imported oil seeds, which we used as feeding-stuffs, are needed for feeding livestock in the countries from which they come. During the war we have cut down imported feeding-stuffs to a minimum and have still kept up the number of milch cows and have reduced beef cattle very little. But, if the number of cows is increased after the war, we shall not be able to supply all the concentrates that they will need, unless yields per acre at home rise or a considerable volume of feeding-stuffs are imported.

For balancing farming a certain amount of roots and grain must be grown; cultivation of sugar-beet is now so fitted into our system of agriculture that it would be inadvisable to give it up. How much cereal, roots and sugar-beet should be grown in any area is a technical question, when once the guiding principle of maximum production of milk, vegetables and fruit is accepted. However much we expand production at home, we shall have to import a large amount of the cheap and portable cereals and sugar.

The Contribution of Science

Whatever plans are made, the world needs more food. The use of good modern equipment and methods would raise the output considerably, even in Great Britain, but not enough to meet requirements. The whole of biological science can help. In the first place, it is not only a matter of getting as much as possible out of the soil; we must put it back again. We are now realising that fertile soil has a life of its own and that maintenance of fertility is not merely a matter of keeping up the concentration of certain chemicals. It involves the action of moulds on organic materials; some moulds help to form humus, while others injure plants. We know little as yet of the influence of chemical fertilizers on beneficial and on harmful moulds. We need to know more about the utilisation even of the simple chemicals; how far can the phosphate that we apply be used by plants? Further investigations are needed into methods of restoring eroded soil and of preventing further erosion.

The increase of the food supply of the world must not impose a drain on the world's capital. Before the war, Britain imported 390,000 tons of phosphate and 200,000 tons of potash, as such, each year and even more in the form of feeding-stuffs for animals; the equivalent of 150,000 tons of rock phosphate and 80,000 tons of potash were poured into the sea each year. If the world should adopt our water carriage system, the deposits of phosphate and potash would not stand the strain. We must either devise methods of saving sewage or be prepared to transmute the elements on a large scale.

Organic chemistry now offers an arsenal of compounds that will kill pests. The organic mercury compounds have been very useful in reducing seed-borne diseases; but the success of D.D.T. (dichloro-diphenyltrichlorethylene) in killing insects raises hopes of some compound as lethal but more selective; something that will not kill bees as well as pests. Animals can be immunised against plagues; the modern methods of immunisation against rinderpest give cattle lifelong protection without risk. Natives of West Africa need no longer depend on naturally acquired immunity, with its 60 per cent. mortality.

TABLE II

Amounts per week	All meat, excluding poultry	Eggs, number	Milk	Cheese	Butter	Citrus fruits	Tomatoes	Cereals and flour	Feeding Stuffs	
									Protein	Calories
Adequate diet	28 oz.	3·5	7 pt.	5½ oz.	12·5 oz.	16 oz.		70 oz.		
Pre-war consumption in Britain	41 oz.	3·4	3·3	2·7 oz.	7·5 oz.	4 oz.	4·9	100 oz.		
Per cent. imported	46	47	0·6	78	92	100	65	78	27	23
Cost of imports million pounds	93	13·5		56		9·7	5·7	5·8	30	

Great improvements in food supply have come from the introduction of food plants from other countries. Three hundred years ago the potato brought cheap Calories and vitamin C for the winter months to the people of Europe ; at present soya beans are supplying fat and protein to an ever-spreading area. The main line of advance at present is the improvement of existing strains, comparable to the breeding of wheats that are resistant to disease or will ripen in the short summers of the high latitudes. But now we understand better what we need most to look for—plants or animals, that will give a good return of the requisite Calories, first-class protein, vitamin A, C or D, riboflavin or calcium, and are palatable. One of these is food yeast—*Torolopsis utilis, var. major*—which provides first-class protein, riboflavin and other vitamins of the B group and has a pleasant nutty flavour. Like animals, it must be fed on vegetable and mineral food—molasses and ammonium salts. As it does not waste energy in walking about and in keeping its temperature above that of its surroundings, it converts much more of its food into food for human consumption—about 60 per cent. of carbon and over 90 per cent. of the nitrogen. This *var. major* is even more significant. Hitherto we have depended, in breeding plants and animals, on chance favourable variations ; but this variety, which has large cells that can be centrifuged down rapidly, was deliberately made by treating yeast with camphor.

Methods which will spread a local or temporary superabundance over a wider area or time must be developed. Canning, freezing, dehydration, various types of processing and methods of converting commercial and domestic wastes such as fish offals into feeding-stuffs should be improved and more widely used. By these methods buffer stocks can be built up, not only of the non-perishable foods such as grain and sugar, but also of milk products, vegetables and eggs. But these processes should not take the place of local cultivation and should not be used without thought of the third purpose of food. The egg, once the yolk and white are mixed, has from the days of our childhood been the by-word for irreversibility ; dried eggs may have all the nutritive value of fresh eggs, but the contrast of texture and flavour of fresh eggs—boiled, poached and fried—can never be restored. Dehydrated minced meat and fish are not as interesting as fresh meat and fish. And dehydrated vegetables keep their nutritive value and flavour for a matter of months only, unless they are stored in an inert gas in air-tight containers.

In Britain cows get two-thirds of their Calories from grass ; more milk involves better use of grass land. First, more and better grass can be grown by improving the type of grass and by periodically ploughing up grass land. Second, grass grows best during the early summer ; there is abundant green food for cows then and their milk contains much vitamin A and D ; in the winter they have to live on preserved grass, roots and concentrates, and they give less milk containing less vitamin A and D. We can either improve the methods of preserving grass, so as to retain its nutritive value, or we can concentrate on producing milk in the summer and condense or dry the surplus summer milk for use in winter. The second is the most economical method, but it will be difficult to convince the average consumer that preserved milk is as good as fresh.

Then the cows themselves can be improved. When a cow's yield of milk is low, the proportion of its food that is used up in keeping the cow is high and the return of human food for feeding-stuffs eaten is low. The number of high yielding cows can be increased rapidly by breeding by artificial insemination from bulls of high yield pedigrees. Tuberculosis which reduces a cow's yield, even when it does not make the milk dangerous, must be eliminated ; with 40 per cent. of cows infected, this will take many years. Contagious abortion, which renders some 10 per cent. of cows sterile, and mastitis, which reduces milk yields by a further 10 per cent., might be prevented also.

Control

Expansion of the food supply of the world as a whole or of a single country, would need control in order to ensure that the foods produced were those needed in order to improve nutrition ; in a scheme embracing countries the control would have to be international. International systems of control of food supplies have been attempted in the past ; some have succeeded. All have aimed at restriction ; inevitably, because effective purchasing power did not keep pace with production. A concerted effort to raise food supplies, such as that proposed by the Hot Springs Conference should, after a latent period of a few years, lead to a steep rise in output. Such a rise would be followed by a crisis of overproduction that would eclipse that of 15 years ago, unless effective purchasing power expanded at the same rate. Extension of social services, as contemplated in the Hot Springs' report, would not be sufficient. The provision of free meals to school-children, as proposed in the White paper on Social Insurance, would cost £60 million ; this is not more than two-thirds of the pre-war cost of our meat imports alone and under $\frac{1}{10}$th of our total food bill ; it would not raise food consumption by 10 per cent. Regarding the matter from the producer's point of view, a farmer has to plan for several years ahead ; he must have an assured market for his produce. We cannot, for example, expect our farmers to breed larger herds of high yielding cows, unless they are assured that people will be able to buy the milk in years to come. A body organising and stimulating food production, whether its sphere is world wide or national only, should co-operate with or form part of an organization adjusting the distribution of effective purchasing power.

Rationing of scarce food stuffs would be needed to ensure that those who most needed them would benefit from increased food supplies. In Britain milk is not rationed on account of a fall in the supply—milk output has risen and the consumption of liquid milk has risen by 10 per cent. during the war—but, in order to reserve enough for the priority consumers—pregnant women and children ; if their prior claims are to be met in the future, rationing will be needed until the supply of milk rises.

An international body controlling agriculture,

which is by far the world's biggest industry, would have a decisive influence on economic developments and could initiate an expanding economy, based on nutrition. The expansion of agricultural production would also create a new demand for manufactures—agricultural implements and household goods—and the development of power stations in connection with irrigation. A precedent, on a smaller scale, can be found in the Tennessee Valley Authority. In this case the primary object was not better nutrition, but control of waterways ; but the Authority has come to have a decisive influence over agriculture, conditions of employment, education, health and recreation throughout the Tennessee Valley.[1]

In the narrower field of immediate home affairs, good nutrition depends on housing ; without the room and means for cooking it is not possible to prepare good meals for a family. The most serious problem directly the war ends will be to find housing for men and women who are returning to civilian life. The amount of temporary housing that can be erected is limited ; many families will have to crowd into existing houses with cooking accommodation for one family only. A good nutrition policy cannot be divorced from a good housing policy.

Finance

It is not possible here to enter into details of organisation, but certain implications must be considered. The necessary implements, the new seeds and livestock would cost far more than the peasants, most of them already deeply in debt, could afford. Still more capital would be needed for large scale irrigation such as would be needed to bring a large new area in India under cultivation and ensure sufficient water for much of the rest, or to exploit the resources of the Danube basin ; more again to set up industries that would employ the surplus agricultural population. The peoples that most need this capital are not in a position to make any return for it without, at the same time, sacrificing the very object for which capital is needed—improvement to their standard of living. These changes can be achieved only through the continuation of a lend-lease system to supply the munitions of peace.

Education

Education in nutrition has two objects : first, to teach people to choose what is good for them, and secondly, to teach them to tell their Government to aim at getting what is good for them. Education will do little good if it teaches people to regard their daily food as a supply of the required nutrients—have I had my quota of riboflavin ?—they should eat food to enjoy it. The task of education is to induce people to enjoy what is good for them. Preferences are largely a matter of habit. For the coming generation school meals will have done much to inculcate good habits ; but we cannot wait for this generation to grow up. It is more difficult to educate adults, but it is adults who decide our policy now.

During the war the Government has been able to change the supply and distribution of food as a matter of necessity, without consulting the people. But in peace time the Government policy depends on popular support ; a policy that aims at improvement in nutrition will not be adopted unless people understand that it is possible, and that the changes and temporary restrictions that it involves are worth while. The present is a most favourable time for education about nutrition, for people have been compelled to think about their food and to make some changes in their diet ; they have seen the science of nutrition applied and have realised that it is neither a collection of fads nor something that has no bearing on their lives. Education must keep this obvious relation to every day life. It should not deal with strange diseases with oriental names, such as beri-beri ; not even with severe diseases, such as tuberculosis —that is to appeal to the hypochondriac. The points to stress are those that will appeal to the healthy man ; the growth and development of children, vigor and a capacity to enjoy life.

The change of habits involved in improvement of nutrition must overcome a deep-rooted conservatism. We should realise, however, that this conservatism has been a most valuable protection against false economy on food and against fads. It is tradition and not any knowledge of food values that keeps up a standard of food that could ill be afforded and resists the voice of the faddist, charm he never so subtly. Practice has been so very much sounder than theory that we may wonder whether habits are not based on some instinct. We know that rats can choose a diet that will give optimal growth with a 13 per cent. saving on diets chosen in the light of human science ; may not human beings have something of the same guidance ?

Some prejudices, such as the objection to tinned food, were originally based on good grounds. At one time the foodstuffs used were unwholesome and the canning processes unsanitary ; these objections are no longer justified. Not all habits have such a respectable origin. There is the addiction to strong pickles and spices, which are first taken to add interest to dull and tasteless food and are continued when the blunted palate will respond to nothing else. The demand for more than their share of meat by adult males, possibly hard working, is due to the idea that eating meat is manly, far more than to any false theories about the source of muscular energy.

There should be no difficulty in persuading people to eat more dairy products, more fruit and even more vegetables. But there will be a storm about flour. Colour is no criterion of the nutritive value of flour ; it is better to talk in terms of the degrees of extraction. In making 70 per cent. flour, the white flour that we had before the war, 30 per cent. of the grain, which contained nearly all the fibre as well as most of the vitamins, was discarded ; the National Wheatmeal Flour contained, until recently, 85 per cent. of the grain with the minimum of fibre ; wholemeal bread contains over 90 per cent. of the grain, with far

[1] For some details of organization and a picture of what has and might be done, see :

The T.V.A. : Lessons for International Application. H. Finer. International Labour Office, Montreal, 1944.

T.V.A. : D. E. Lilienthal, Penguin Special, 1944.

Food and Farming. Yates and Warriner, Oxford University Press, 1943.

Palestine, Land of Promise. Lowdermilk, Gollancz, 1944.

more fibre. Flour is still the chief single foodstuff in British diets; before the war it supplied over one-third of our Calories. The ratio of units of vitamin B_1 to Calories in 70–72 per cent. flour is under 0·1. Unless some other foodstuffs are eaten, that supply a large amount of this vitamin—and such foodstuffs are few—the ratio of vitamin B_1 to Calories in the diet is below the optimum and may be little above the beri-beri level. Other vitamins of the B group are lost in making 70 per cent. flour, and we are not in a position to put them back as synthetic vitamins until we know and can make all the possible vitamins in grain.

Much of the vitamin B_1 is in the scutellum, which forms a very small fraction of the grain. It is claimed that with changes in milling processes it may be possible to retain a large part of the scutellum and therefore of the vitamin B_1 in flour of lower degrees of extraction. But riboflavin and niacine have not this convenient distribution and a large proportion of them would be lost in making such flour. It is true that the fraction of the grain that is discarded in milling white flour is used to feed animals, and that a small part of the vitamins comes back to us in milk and meat. But, if animals are to be fed on grain, let us frankly grow or import grain as feeding-stuff and not subtract an essential part of our food without reducing the volume of imports. The allegation that the flour now in use disturbs digestion is unfounded; patients with gastric ulcers tolerate it at least as well as white bread. It does cause a freer action of the bowels and has apparently led to a highly desirable fall in the use of aperients. The claim that the use of *wholemeal* flour led to an increase of rickets in Ireland is based on very flimsy evidence.

The objection to wheatmeal flour is mainly due to people's preference for food to which they are accustomed, but also, in part, to differences of outlook. Some people like bread with a flavour, others regard it as a neutral support or filling for other foods and like it tasteless. Some judge bread by ease of spreading butter on it, others put bits of butter on chunks of bread and dislike crumbly bread. Quite apart from the loss of vitamins owing to the low degree of extraction of the flour, little could be said for English white bread, with its crust tough instead of crisp and its crumb doughy instead of spongy. A satisfactory loaf can be and is baked from flour of any degree of extraction; the attraction of a well baked loaf would far outweigh any prejudice against its colour. But it should be realized that the difficulty in baking a good loaf with wartime flour has not been due to the higher degree of extraction, but to the use of a high proportion of English flour.

TABLE III

COMPOSITION OF FLOUR, PER 100 GM.

	Protein Gm.	Vitamin B_1 I.U.	Vitamin B_1 Mgm.	Riboflavin Mgm.	Niacine Mgm.	Iron Mgm.
National Wheatmeal	10·7	100	300	1·3	17	2·07
White flour	10·7	27	81	0·3	0·6	1·06

APPENDIX 1.—VITAMINS CONSIDERED TO BE NEEDED BY HUMAN BEINGS

	Other Names	Action	Disease Associated with Deficiency	Daily requirements of moderately active adult man. Optimum standard
A		Forms visual purple. Controls structure of cells on surfaces. Possibly controls metabolism of fat	Impaired dark adaptation. Changes in skin (phrynoderma) and in front of eyeballs (xerosis) which may lead to ulceration (Keratomalacia) and blindness	5,000 International Units
β-Carotene	Provitamin A	Converted in the body to vitamin A		
D	Calciferol (1)	Controls absorption of calcium and deposition of calcium salts in formation of bone	Rickets in babies and children; in older persons, loss of calcium salts from bones (osteomalacia)	Undecided
	Activated (1) 7-Dehydrocholesterol			

1. Ergosterol and 7-dehydro-cholesterol are converted into vitamins D_2 and D_3 when exposed to ultra-violet light both in vitro and in the skin.

APPENDIX 1.—VITAMINS CONSIDERED TO BE NEEDED BY HUMAN BEINGS—*continued*

	Other Names	Action	Disease Associated with Deficiency	Daily requirements of moderately active adult man. Optimum standard
E	Tocopherol	Regulation of reproductive functions	Sterility	Undecided
K		Formation of prothrombin which is essential for clotting of blood	Uncontrollable bleeding	Undecided
B_1	Aneurin Thiamine	Metabolism of pyruvic acid	Changes in temperament. Loss of appetite. Beri-beri	1·8 mgm.
Riboflavin	B_2	Oxidation of glucose	Sore lips and cracks at corners of mouth (cheilosis)	2·7 mgm.
(3) Niacine; including nicotinic acid, Nicotinic acid amide)	B_2 Anti-pellagra factor	Oxidation of glucose	Pellagra	18 mgm.
(3) Pyridoxine	B_1		(2)	Undecided
(3) Biotin			(2)	Undecided
(3) Panthotenic acid	Filtrate factor		(2)	Undecided
Ascorbic acid C	(Cevitamic acid)	Controls formation of fibres and materials that hold tissue cells together	Impaired healing of wounds Scurvy	75 mgm.

2. Occurrence and nature of any disease in human beings not fully established.
3. Members of the B Group.

APPENDIX 2

For calculation of the nutritive value of diets detailed tables of the composition of foods are indispensable. But a general picture of the contributions made by different foodstuffs to the day's requirements can be obtained from the following data.

Most solid foods that are not unusually fatty supply from 200 to 350 Calories and 10 to 20 gm. of protein per 100 gm. (3 oz.).

The 2,500 to 3,000 Calories and 70 gm. or so of protein, needed by a moderately active adult, will be supplied by about 1,000 gm. (35 oz.) of such solid food.

Vitamin A

Preformed vitamin A is contained in milk (120 I.U. per 100 gm.), butter (1,200 I.U.), cheese (900 I.U.) eggs (400 I.U.).

Green vegetables, roots and fruits contain carotene, which is converted in the body into vitamin A. The proportion of the carotene in food that is absorbed varies. Hence the vitamin A value of vegetables cannot be given precisely. The vitamin A value of the darker green vegetables and of carrots is high (about 5,000 to 10,000 I.U. per 100 gm.). That of the lighter green vegetables ranges from about 1,000 I.U. (lettuce) to 100 I.U. (white cabbage).

Vitamin C

Vitamin C is derived almost entirely from fruits and vegetables which may be classed according to their vitamin C content as follows :

High (40 or more mgm. of ascorbic acid per 100 gm.) : Rose hips (200), blackcurrants (120), most raw green leafy vegetables (50–100), oranges and lemons (50), strawberries (60).

Medium (25–40 mgm. per 100 gm.).

Raw turnips or swedes (20–30), cooked green vegetables (15–30), tomatoes (25), new raw potatoes (20), gooseberries (25), raspberries (25).

Low (0. to 15 mgm. per 100 c.c.).

Old raw potatoes (8), cooked potatoes (0. to 15), lettuce (12), raw onion (9), bananas (10), carrots (5), plums (5), apples (5).

Riboflavin is supplied mainly by milk, cheese, meat, eggs and flour of higher degrees of extraction; niacine by meat and flour, particularly wholemeal.

The chief sources of calcium are dairy products; dried beans contain a relatively high percentage, but the amount in a helping of cooked beans is not large.

WATER-SUPPLY

By Prof. P. G. H. Boswell, F.R.S.

'For the rain it raineth every day
. . . hey, ho, the wind and the rain.'

Disappointed holiday-makers in Britain frequently have occasion to echo the refrain of Shakespeare's Clown, but seldom pause to reflect that the rest of the year might go ill with them but for this inconvenient phenomenon. Rain is, of course, the ultimate source of the country's water supply.

We are all familiar with the atmospheric cycle, which gives us not only the fleeting beauty of summer clouds and the glory of sunrise and sunset, but also the menacing gloom that precedes a storm and the onset of rain or hail. This cycle begins with evaporation, under the sun's heat, from oceans, seas and lakes; and the vapour, in the form of clouds is driven by winds over the land surface. In due course, cooled and condensed, it falls as rain or snow. Mountainous areas, which slow down the warm vapour-laden currents and deflect them upwards, have a greater rainfall than low-lying districts, and the country that fringes oceans and seas tends generally to be wetter than inland regions.

Rainfall is measured by means of standardised gauges, set up under prescribed conditions as regards height above ground, distance from trees and buildings and so forth. Readings are made daily at a fixed hour, and the quantity of rain that has fallen is recorded in inches (or, usually, fractions of an inch). The average monthly and yearly totals for different areas are duly recorded in various official publications (e.g., in our own country, in the annual volumes of *British Rainfall*).

In order to bring to mind the quantities involved, it should be noted that in Great Britain the average annual rainfall varies from 60 or more inches in the mountainous country of Wales, the Lake District, and Scotland, reaching the high record of about 200 inches at two localities: Snowdonia and the head of the river Garry, Inverness-shire, to 20 inches or slightly less in the region of the Thames estuary. In the London district, in particular, it is about 25 to 26 inches.

An inch of rain a year represents a fall of closely 40,000 gallons of water a day upon every square mile of country, or, put otherwise, 101 tons per acre annually.

If the rain fell evenly throughout the year throughout the country, and the demand for water were similarly distributed evenly, most of the problems of water-supply would disappear; and water-engineers and geologists (not to mention parliamentary agents and counsel, who assist in promoting schemes for obtaining water) would lose a more or less lucrative occupation. However, since rainfall and the demand for water are irregularly distributed, many districts are faced by problems which necessitate the collaboration of geologists, who locate underground water, and engineers, who extract and store the supplies.

At the outset, we may remind ourselves that the rainfall of Britain, if it could be made available as required in time and place, is amply sufficient for all the population's needs, for it would furnish several thousand gallons of water per head per day. Set against this figure, we have the present average overall requirement ('overall' meaning that the demands of many industries are included) of only 20 to 30 gallons per head per day. Even if the daily consumption of water rises in the not too distant future to a figure as high as 100 gallons per head, the reserves are obviously ample.

The Water 'Income and Expenditure Account'

It is the duty of the water-engineer to assist in adjusting this unequal distribution of rainfall in both space and time: in space, because the run-off of water from the land surface and the storage capacity of the rocks forming the earth's crust vary in different districts; and in time, because the amount of rain and the consumption of water vary at different seasons of the year. The period from October to March is that of replenishment, and the months of March to October, those of storage and heavy consumption. Therefore the engineer arranges to store the

rain or to utilise nature's storage when and where the supply exceeds the demand, and provides for transport of water from areas of high rainfall (which are often those of low demand) to others where the conditions are reversed. Both kinds of undertaking may be costly, especially if natural storage has to be supplemented by artificial means; therefore we must expect to pay for our water, although instinctively we think of 'water, water, everywhere' and may resent having to buy it.

To return to the rainfall cycle. We can clear our ideas by drawing up an 'income and expenditure account.' The income is a known quantity, for it can be measured in rain-gauges; the expenditure is represented by evaporation, run-off and percolation into the ground, and can be measured in part and estimated in part—in any case, the two sides of the account must balance. We may proceed to consider these items of expenditure in a little more detail. Only part of the rain recorded in the gauges as having fallen on the surface of the earth becomes available for water-supply, for some is lost losses (due to run-off and percolation) can be assessed.

Although the meaning of the term 'run-off' is evident, a further word of explanation may be desirable. Some of the rain runs directly off the surface, forming rills and streams, and some sinks into the soil, subsoil, or underlying rocks, if they are permeable, part to emerge again as springs and part to drain away into the depths. The sum-total of the water which is delivered up by springs or flows off in rivers, constitutes the 'run-off.' The quantity that sinks into the ground varies greatly. To consider the extreme cases, where clays or other impermeable rocks underlie the soil, the percolation is *nil*, and the run-off a maximum, but where the rocks are highly porous or fissured (like certain sandstones and limestones, including chalk), all the rainfall not lost by evaporation may soak away underground, in which case percolation is at a maximum and run-off may be *nil*.

Thus our income and expenditure account appears as follows :—

Income.		*Expenditure.*		
Rainfall	R	Evaporation		e
		Direct surface flow—		
		Shallow, emerging as springs	Run-off	r
		Percolation — Deep-seated, emerging as springs		
		Deep-seated and retained in rocks ('net intake')		p
		Consumption directly from surface by organisms, including man		c
	R			$e+r+p+c$

to us very quickly by evaporation from the ground, especially after hot, dry weather and heavy showers. Estimates show that this loss by evaporation is usually not less than one-third, and may be as much as two-thirds, of the rainfall. An average figure for many districts is about 18 inches. Attempts to measure it exactly by means of evaporation-gauges, which are tanks of water of known superficial extent, from which the loss of water can be directly determined, cannot be regarded as altogether satisfactory, for evaporation from a sheet of water can differ greatly from that over a land area, and the latter again varies according to the type and relative abundance of vegetation and condition of the soil. A more satisfactory figure for evaporation has sometimes been arrived at by difference, i.e. by deducting other known drafts on the rainfall from the total figure, and regarding the balance as loss by evaporation. Obviously, the significance to be attached to the quantity thus obtained depends on the accuracy with which the other

Item c is usually small, although at some dry spots like Aden and Gibraltar, extensive and expensive arrangements have been made to collect and store rain for public water-supply. Elsewhere, especially if the tap-water is hard, people prefer to catch some of the rain—from roofs, etc., and store it as soft water in cisterns and butts to serve for washing, or for gardening purposes. Much more could be done in this way, especially in rural areas.

Overground Supplies of Water

It is evident that items r (run-off) and p (ultimate percolation or 'net intake'), each of which is a very variable quantity in different districts and at different times of the year, furnish the source, and the only source of public and private water-supplies, whether for domestic or industrial purposes (with one minor exception, although most important in its place, to be referred to later under *Juvenile* water. The run-off is utilised widely in

this way. Water-supplies for many towns and cities are taken from rivers, after being filtered and, if necessary, otherwise purified. An outstanding example is the supply for London, where the river Thames and its tributary, the river Lee, provide about 85 per cent. of the quantity administered by the Metropolitan Water Board. Springs yield the necessary supplies in many parts of the country—in places sufficient only for villages, but elsewhere (as at Havant, near Portsmouth, the city of Wells, and the Chadwell and Amwell springs, near Hertford) in quantities amounting to many millions of gallons a day. The conditions that give rise to such springs are outlined below.

River flow, being liable to fluctuate greatly with the rainfall, must usually be stored up at seasons of flood if adequate supplies are to be available during times of diminished flow. Nature effects some of this storage for us, where the shape of the land-surface has resulted in the presence of lakes. Also, many large rivers have provided themselves with storage capacity in the form of the wide terraces of sand and gravel which flank them and represent the debris which was brought down in past ages when their forerunners were more voluminous and powerful. The water that now comes down when the rivers are in flood is in part retained in the interstices of the sand and gravel of the terraces, from which it drains away but slowly. The utilisation of these flat terraces for industrial development and housing and the consequent draining of the sites near great cities is robbing us of valuable balancing reservoirs.

As examples of cities which draw water-supply from lakes, there may be mentioned Glasgow (from Loch Katrine) and Manchester (from Thirlmere).

The engineer improves on nature by adding to the storage afforded by lakes and rivers. In pursuance of the injunction embodied in the familiar toast of an engineering club, he blasts the rocks and dams the rivers. In some cases, he only finds it necessary to build an embankment or construct a wall-like dam at the outlet of a lake in order to raise its water-level and thus give a better adjustment between winter and summer supply; in this way the extent as well as the depth of the lake is increased. Examples of such improvements on natural storage are Manchester's scheme at Hawes Water in the Lake District and the scheme of the Aluminium Corporation, Limited, at Llyn Eigiau, near Dolgarrog, North Wales. Alternatively, the engineer impounds a river and thus turns it into a lake, at the same time arranging for a certain amount of the water (compensation water) to escape down the river bed in order to satisfy riparian rights, the anglers' urge and hygienic requirements in the lower reaches of the stream. Extensive and often very beautiful artificial lakes are then formed, although sometimes at the cost of submerging farms, famous old inns and valuable agricultural land. Examples of such undertakings are those of Liverpool at Vyrnwy in Montgomeryshire, Birmingham at Rhayader (Elan Valley), Radnorshire, Birkenhead at Alwen, Denbighshire, and the joint scheme of the Derwent Valley Water Board (for Sheffield, Derby, Leicester, Nottingham, Leicestershire and Nottinghamshire) in the Derwent Valley.

If the area impounded is small, the dam which is built across the river can be constructed of earth, with a core of puddled clay or concrete, but large schemes necessitate the building of massive dams of masonry or concrete, sunk down into a firm foundation of solid rock and tied, if possible, into the rock at the sides. The whole area of the catchment of the river should previously have been geologically surveyed, and special attention given to the area which would become the reservoir itself, in order that leakage might be prevented or minimised. The character and distribution of the various rocks that crop out at the surface or lie beneath the soil or peat, as well as their disposition, must be known as accurately as possible, for permeable formations must be rendered impermeable by covering them with clay or impregnating them with cement; moreover, rock-breaks or fissures of any size must be stopped up. In selecting the dam site itself, considerations of safety and cost demand a detailed geological survey, supplemented by trial borings and trenches. If the valley narrows, the dam can be reduced in length, and if solid rocks reach the river banks and form its floor, the conditions become ideal. Great care has to be taken in determining the thickness and distribution of surface deposits like peat or glacial Drift, the latter being composed of sands, gravels, and clays, often containing large boulders—a legacy from the time when glaciers swept over the country during the great Ice Age. Dams cannot be safely built on foundations of these unconsolidated materials, and only in exceptional cases (where stiff clays occur) can their ends be safely tied into the valley flanks. Deep, and therefore expensive, excavation of the Drift deposits down to the rock floor is often necessary.

As failure to give adequate consideration to these factors may afford opportunities for subsequent disasters by the bursting of dams, it is a tribute to the skill and care of engineers to record that such calamities have very

rarely occurred in this country. Prevention being better than cure, it pays to spend time and money on a thoroughly scientific investigation of the site of an impounding reservoir before other work is begun upon it. As an example, we may refer to the case of the world's highest dam, known as the Boulder Dam, completed only recently. It is situated on the Colorado River, in Black Canyon, Nevada. The height of this mass-concrete structure is 726 feet, and its width is 660 feet at the base, and 45 feet at the top. An influential committee of engineers and geologists was appointed by the United States Government to investigate and report on the proposals and to suggest a site for the dam. Subsequent work showed that all their predictions and warnings were justified. The total cost of this great and successful undertaking was £15,350,000; the total cost of all geological and exploratory work, including fees, was £165,000, or about 1·1 per cent.

Other similar examples could be cited, but this alone is sufficient to emphasise the fact that nowadays engineers are responsible for collecting and controlling very large quantities of water in the public interest; which brings to mind the double-edged compliment paid by a distinguished member of the Bar to an equally distinguished (and rosy-faced) water-engineer—whom he described as a man who could safely be entrusted with any quantity of water.

For obvious reasons, impounding schemes are nearly always located in hilly or mountainous regions, where rainfall is relatively high, land is cheap and often tends to be barren, and dwellings are scarce. There, too, the rocks that crop out at the surface are usually hard and frequently impervious. But inasmuch as big cities, which alone require supplies of the magnitude that large impounded reservoirs furnish, have rarely arisen in such regions, but rather develop on lower ground where communications and access are easy, lengthy transport of the water is necessitated. Fortunately, as the areas of supply are relatively high, the flow of water from source to market is aided by gravity (when such resources are termed *gravity supplies*), but the building of the pipe-lines and the keeping of the pipes clear of slime and plant growths is still costly. The pipeline from the Alwen reservoir to Birkenhead is 42½ miles in length, and varies between 19 and 33 inches in diameter; that from Vyrnwy to Liverpool, 65 miles and 39 to 42 inches in diameter; from Rhayader to Birmingham 73½ miles and 60 inches and 42 inches in diameter; and from Thirlmere to Manchester 96 miles and 36 to 48 inches in diameter. When, 40 years ago, the Vyrnwy dam, 84 feet in height, was constructed, it established a record as the world's highest dam: this may now be contrasted with the Great Boulder Dam, already mentioned, 726 feet in height.

Only large towns or groups of neighbouring towns can afford to embark on water-supply schemes of this type; indeed, they are compelled to go to distant sources because the growth of industry and population has rendered local supplies of water inadequate. In many cases, however, they continue also to use the local resources. Smaller communities rely upon local supplies of water unless they happen to be near one of the large aqueducts of the type just mentioned, when they may be able to buy bulk supplies from their big brother. For the largest industrial uses of water, such as hydro-electrical schemes for power generation, and schemes of irrigation and reclamation, only gravity supplies are adequate.

The local supplies may be derived from rivers and springs, as already noted, or from underground sources. Thus we come to the question of item *p* of our income and expenditure account above, that of the rainfall which percolates deeply into the earth's crust, there to be stored in suitable rocks.

Underground Resources

Attempts have been made to determine the quantity of rain which can percolate through different kinds of rock. Percolation gauges have been made by isolating cubes, usually of about 3 to 5 feet edge, of soil, subsoil and underlying rock, below which metal trays collect the rain which has passed through the cubes. The results obtained vary so greatly that the value of percolation gauges has been questioned. Certainly, such gauges can hardly reproduce average natural conditions over areas many square miles in extent. Actually, it happens that rain percolates into the ground by taking advantage of cracks and crannies in the rocks as well as the pore-spaces between the grains. In the case of some rocks, such as chalk and limestone, little rain is actually transmitted through pores, the bulk finding its way downwards along bedding-planes, 'joints' and other fissures.

Sooner or later in its downward passage, the water is stopped by an impervious bed when, allowing for such movement as it may be able to make sideways, it tends to fill up the cracks and pores of the overlying permeable rock. Thus the rock becomes a reservoir for storage of water, but in the sense of a reservoir occupied as to 70 or 80 per cent. by more or less compact solid material and 20 to 30 per cent. by water. We have then a 'water-bearing formation,' or, as

the Americans say more shortly, an ' aquifer.' The best examples are furnished by beds of sand, gravel, sandstone, conglomerate (pudding-stone), limestone and chalk. The manner of arrangement of these beds of rock underground (for they are only rarely horizontal, but are often tilted and are sometimes bent into saddles and basins) determines the ease or difficulty with which the water is stored and can be recovered subsequently by man. Wells or boreholes sunk from the surface to the aquifer then furnish the means

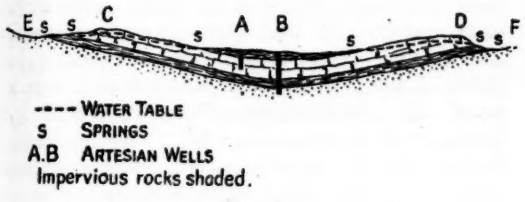


FIG. 1.

of obtaining a supply of water. If the water contained in the aquifer is under pressure, it may overflow at the surface as an *artesian well* (see Fig. 1, A) ; otherwise it stands in the well or borehole, from which it can be extracted by pumping or other form of lift.

As the underground reservoir tends to fill up after wet weather, and drain away to some extent during dry spells, there is a seasonal fluctuation in water-level in many wells ; usually the level is highest in March and lowest in October. In times of drought the level may fall below that of the bottom of the well ; hence arise some of the difficulties of serving rural communities by means of shallow wells.

THE WATER-TABLE

Clearly, it is an advantage to know as much as possible about these fluctuations in water-level, both for the purpose of locating new wells and safeguarding the life of old ones. Therefore arrangements are made for recording levels at different seasons of the year, both when pumping is in progress (pumping-level or working-level) and during its cessation (rest-level or standing-level). In porous formations like sands and sandstones the surface of the underground water, recorded by the rest-levels, is termed the water-table or surface of saturation. It can actually be traced if tunnels are driven through the rock. In fissured rock like chalk it is a discontinuous surface, points on which are given by the water-levels in wells and boreholes or in fissures ; it cannot be seen in the rock itself, but is none the less a valuable concept. If there are sufficient records, a contoured map of this underground water-surface can be made, just as the surface of the earth can be contoured. Also, corresponding to the hills, valleys, pools and watersheds of the overground surface, we are able to locate elevations, depressions and underground watersheds in the water-table, which may or may not lie vertically beneath their surface analogues. The slope of the water-table is usually gentle, being often about 25 to 30 feet in a mile. From such contoured maps, we can then determine the shape and size of underground catchment areas—an important matter because they often differ in extent from the overground catchments. Also, we can predict the water-level in a well at a new, unexplored, site, estimate the quantity of water obtainable, and the likely seasonal fluctuation of water-level ; and we can determine the best direction in which to drive underground headings from the well. The degree of accuracy attainable in these investigations depends, of course, on the number of records available. In the Greater London area, for example, several thousand water-levels have been used in plotting the water-table, with the result that knowledge of underground conditions is here unusually extensive and detailed.

The effect of pumping water from a well is to lower the water-level locally (see Fig. 2), the form of the surface of saturation then taking an approximately conical shape with the apex at the bottom. The diameter of

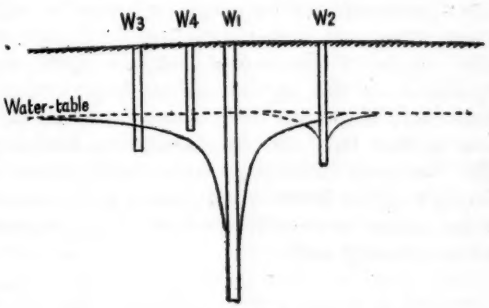


FIG. 2.

the cone varies according to the quantity of water in the rocks, and the ease with which it can travel through them ; also, it varies with the intensity of the pumping. Heavy pumping (other things being equal) causes a big depression of the water-table and therefore a cone of exhaustion of considerable diameter ; for example, pumping at the rate of 6 million gallons a day may cause a widespread lowering of the water-surface which is felt at points $\frac{3}{4}$ mile distant ; here the diameter of the cone of exhaustion would be $1\frac{1}{2}$ miles. Less intensive pumping, if operating on a less permeable formation, may give rise to a similar widespread effect.

Each well pumped therefore produces a dimple in the water-table, which fills out again if the well is 'rested,' the period for recovery lasting from a few hours to a week or two, after which the water again reaches its rest-level. The speed of restoration depends on the ability of the rain-water to sink into the earth and through the rocks in time to replenish the 'reservoir.' In times of drought, recovery is delayed, with the result that the water-table is usually lowered by many feet for the time being.

If wells are widely spaced (say two or three miles apart) and rainfall is maintained, no permanent lowering of the water-table takes place, but if heavily pumped wells are close together, their cones of exhaustion interfere, levels are lowered and each well gets less water than if it had stood alone (see Fig. 2, W1 and W2). Moreover, if one well is deeper than its neighbours and can be heavily pumped (as W1), its cone of exhaustion may be so extended that the water-surface is reduced in neighbouring wells (as W_3), which may even run dry (W4). The old tag, stolen waters are sweet, comes to mind, but it is not altogether apposite in the present instance because of the legal principle that, crudely put, there is no property in underground water. Unless, therefore, a well has been given statutory protection by Parliament (see below), it is lawful for anybody to sink another well close by, assuming that he can acquire the necessary small area of land in which to locate it. He may thus rob the original well of part or the whole of the water. Apart from any question of the legality of such procedure, however, it follows from what has been said above that it is certainly not good business, for the new invading water-undertaker is likely to get a better yield from a well located some distance outside the cone of depression of an existing well.

Dangers of Overpumping

In congested industrial areas where there has been a lack of planning and co-operation, this policy of 'beggar my neighbour' has persisted, with the result that the accessions from rain cannot keep pace with the extraction, and there has been in consequence a steady fall in the level of the water-table. The area is then said to be overpumped. Many industrial districts of Britain have suffered in this way, noteworthy examples being those of London and Birmingham. In the London region, the water-bearing horizon is the Chalk (together with the overlying Thanet Sand), which has been folded into basin-like form (see CD in Fig. 1, which would represent conditions in the western part of the basin) : thus the Chalk, which descends beneath London from the surrounding hills, is fed by the rain falling on the chalk-uplands of the Chilterns and North Downs. In 1835, apprehension was already being felt because the increase in the number of wells had led to a lowering of the water-table at the rate of about 1 foot a year. From time to time thereafter, attention was drawn to the dangers lying ahead if the practice continued, but Victorian individualism was too strong for co-operative effort, and the voices continued to cry in the wilderness. A century later, although 531 out of 1,080 deep wells in the metropolis had had to be abandoned, the fall in water-level was proceeding in parts of London at the rate of 4 to 5 feet a year. In places, there was a recorded depression of as much as 300 feet in 60 years. Unfortunately, the trouble does not end there, for one effect of overpumping is to increase the danger of pollution, because water is drawn in from the Thames estuary, thus causing the abandonment of wells which had become brackish or otherwise contaminated.

Dumb Wells and the possible replenishment of Underground Supplies

In engineering undertakings other than those for recovering water, the formation of cones of exhaustion may, in certain circumstances, prove of value, as the following incident indicates. Overlying the basin of Chalk beneath London are thin beds of sand and clay, and then a deposit of stiff clay, the London Clay, several hundreds of feet in thickness. This combination of favourable geological conditions might almost be regarded as an early dispensation of Providence to assist the metropolis of to-day ; for it not only resulted in providing copious stores of pure water close at hand, but afforded ideal conditions in the thick clay for the development of London's ramifying underground communications, whether needed for public utilities such as gas, water, electrical or postal services, or for passenger-transport. During the construction of one of the tunnels for a tube-railway, the normally impervious London Clay was found to contain a seam of sand which became very troublesome to the engineers because of the water it discharged. A member of H.M. Geological Survey, who visited the works, was consulted about a possible remedy, and made the suggestion, somewhat startling to the engineers, that a boring should be sunk in the floor of the tunnel down to the Chalk, in order that the water could drain away. But, it was objected, the Chalk under London was known to be full of water under pressure

from the neighbouring hills, only waiting, so to speak, to flood the tunnel if opportunity offered. When, in reply, it was pointed out, that although such were the *natural* conditions, the effect of heavy pumping from numerous wells in the neighbourhood had created an artificial state of affairs in which the water-level was depressed and the upper layers of the Chalk were drained, the advice was adopted—and with success. In technical language, a dumb well was produced, i.e. one which did not yield water, but served to dispose of it (see Fig. 2, W4).

Arising out of this knowledge of conditions under London, and the difficulty of maintaining the yield of wells, has come the suggestion, from time to time, that the underground stores of water could be replenished by diverting river-flow into giant dumb wells sunk for the purpose into the Chalk. They would necessarily have to be huge wells, for the rate of absorption of water by an aquifer is a slow business. Experiments to this end have been attempted on a small scale, as in the Lee valley, and the yield of wells thus locally increased, but no long-term tests have been carried out. If this procedure is adopted, however, two considerations must be borne in mind. First, all water so used must first be filtered and thoroughly purified; and secondly, the cost of the undertaking should be a regional or national matter, for it would be unreasonable to expect any individual water-undertaker to incur considerable expense in order to benefit the community at large as well as himself.

The Form of the Water-Table

The above discussion of the behaviour of the water-table may have given the impression that it never reaches the surface, but a moment's thought will show that this is not the case. In the first place, it may be sufficiently near the surface, especially after heavy rain, to be cut into by depressions of the land such as river valleys or hollows. In that case, the emergence is marked by springs, seepages or marshy tracts. In the second place, the impervious rock-layer which forms the bottom of the aquifer may crop out on the sides and floors of such depressions, when numerous springs will be thrown out at, and a little way above, the junction of the permeable and impermeable layers (see Fig. 1, S) Similarly, since the sea-basins are but large hollows in the earth's surface, the water-table can emerge on the sea-shore or in the cliffs behind, and the underground 'reservoir' of fresh water can then be regarded as overflowing into the sea (see Fig. 3, A). Thus we often find good springs of fresh water appearing on the shore between tide-levels.

Spring flow (and that of intermittent streams, or 'bournes') is often affected by changes in atmospheric pressure; a sudden fall in the barometer is accompanied by increased flow. Perhaps no better example than this could be cited to indicate how sensitive is the water-level and how quickly the water-table can respond to natural conditions.

It has been found by actual observation, also by imitation of the conditions experimentally in the laboratory, and, further, by treating the matter as an ideal mathematical study, that where a permeable rock forms the coast, the sea-water extends beneath the land, its surface being of parabolic form, concave upwards (see Fig. 3, AB). The

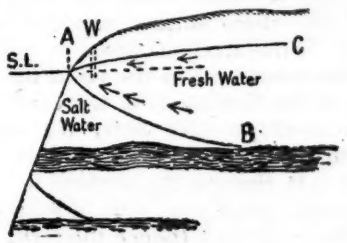


Fig. 3.

fresh water under the land (or ground-water as it is often termed) thus rests on the salt water, its upper surface also being of parabolic form, convex upwards (Fig. 3, AC). Diffusion of the one kind of water into the other proves from observation to be less rapid than one might expect, probably because of the persistent seaward movement of the fresh water under pressure from ground-water in the adjacent land. As the tide rises or falls it backs up or releases the fresh water, and the water-table thus rises or falls in sympathy, by an amount which decreases as we proceed inland. Hence, a maritime well (Fig. 3, W) often shows a fluctuating water-level, when it is termed an ebbing well. If such a well is heavily pumped, the cone of exhaustion may extend downwards until the sea-water surface is affected, so that it yields a mixture of fresh and salt water. Many maritime wells, for example, in areas like Merseyside, the Thames estuary or the South Coast, especially where there are numerous industrial undertakings, have become brackish and useless with the passage of years. If frequent analyses of the water are made, however, the danger can be detected at an early stage by the slight increase in sea-salts; and if steps are taken to reduce the pumping or to rest the well at intervals (and most importantly, to persuade neighbouring undertakings to do the same) trouble may be postponed for a long time.

One other source of underground water-

supply calls for mention. In certain districts nowadays, the increased demands have led to the use of the water pumped, or drained, from certain coal mines or metalliferous mines, despite the expense involved in purifying such supplies.

Juvenile (Plutonic) Waters

In the foregoing paragraphs, the ultimate source of all the water-supplies discussed is atmospheric water, i.e. rain. But at certain places on the earth's surface we have reason to believe that there is another source of water—from deep-seated rocks. This is small, it is true, in comparison with supplies from rain, but important in such an area as the great artesian basin of East Central Australia, where surface supplies are often absent. This kind of water is believed to have been enclosed in the rocks in the early stages of the formation of the earth : hence it is termed juvenile water (or sometimes, because of its depth and associations, plutonic water). It rises to the surface in places as hot springs, often with salts in solution, as at Carlsbad and Bath (hence the term, mineral springs), its composition differing notably from that of ground-water, e.g. in freedom from chlorine. Borings several thousands of feet in depth in Australia have tapped these underground supplies, which in many places are hot enough to be used for making tea or cooking, and are under sufficient pressure to rush up the borehole and overflow at the surface. Probably the juvenile waters support and raise the ground water to the surface so that a mixture of the two types is yielded. Although beginning at a figure as high as one million gallons daily, the yield often falls off, and wells in time cease to flow.

Protection

The general protection of gathering grounds and of wells so as to ensure that water-supplies will not be polluted has yet to be established by law. Also, no general measure of protection, as regards the quantities yielded by underground supplies, has been given by Parliament to public water undertakings up to the present time, but in a few cases Parliament has given specific protection for a radius of 1½ or 2 miles around pumping stations. On the other hand, the rights of the individual citizen or industrial firm have often been safeguarded, for it has long been the practice of Parliament, when sanctioning new water-works, to afford protection to existing wells situated within a specified radius (often 2 miles, but in recent times more often one mile), by ensuring that the owners of such wells shall continue to obtain water at the same cost as before, e.g. by having their wells deepened for them, or the reduction in yield made good by piped supplies. But the onus of proving diminution of supply is placed upon the aggrieved party.

Further, Select Committees of Parliament have given specific protection to owners of existing wells, or even spring supplies, outside the general area of protection mentioned above, sometimes for a distance of several miles. As an extreme example, there may be mentioned the prohibition placed on the South Staffordshire Water Company in the Act of 1908, against sinking a well within 7 miles of the Parish Church of Burton-on-Trent. It might perhaps be thought that this was because the special qualities of the water of that town are so highly esteemed in certain circles !

Apart from such particular statutory protection, the position is that the owner of land may by pumping attract the water from beneath his neighbour's land, though by doing so, he does his neighbour great damage. Such damage is *damnum sine injuria*—hurt, but not legal wrong—and his neighbour has no remedy, except possibly in the case of a right to have the surface of his land supported by underground water, which may perhaps be gained by prescription. If, however, the underground water can be proved to flow in a known and defined channel (which is no easy matter) then the same law applies to it as to a river on the surface, namely, each owner through whose land it passes must allow it to flow unimpeded and may only abstract from it a quantity of water sufficient for his reasonable use.

In the recently issued White Paper (Cmd. 6561) on a National Water Policy, the Government propose that the powers of the Minister of Health shall be extended in such a way that he may make an order, after a local Inquiry, scheduling any area within which the conservation of water resources, surface or underground, is necessary in the public interest, whether for the protection of public water supplies or for that of industrial or other uses. The order would prohibit the additional abstraction of water from the area without the consent of the Minister (except in certain cases specified in the order, e.g. abstraction by a private individual for his own domestic purposes). And there is also the proposal that it shall be made an offence to allow underground water to run to waste from borings or to pollute it.

Yield of Wells and Boreholes

The output of wells and boreholes varies within wide limits. Obviously, the larger

the diameter of the well or borehole and the larger and more numerous the underground galleries which are driven from such a well, the greater is the yield obtainable. Chiefly, of course, the yield of water depends, apart from the rainfall, on the nature and arrangement of the rocks of the district. Therefore, a geologist should always be consulted in locating a site for water supply.

The highest yields from individual wells in this country come from the Chalk, where in exceptional cases as much as eight or ten million gallons daily have been recorded. Many wells have yielded 6 m.g.d., and still more furnish 2 to 3 m.g.d. ; but an average figure for large Chalk wells, taken over an extensive area in south-eastern England, is about 1½ m.g.d. Groups of connected wells (say 4 or 6 in number) in the next most prolific British formation, the red sandstones of Triassic age in the Midlands and Cheshire, have yielded 3 to 6 m.g.d., but such outputs are not common ; usually the yield varies from ½ to 2 m.g.d. The significance of these figures becomes clearer if it is remembered that, with a consumption of 30 gallons per head per day, a yield of 6 m.g.d. suffices for a population of 200,000. But it should also be noted that nowadays a single large industrial works may consume as much as 6 m.g.d.

The quantity of water obtained from wells, i.e. from underground resources, is in the aggregate much less than that from overground supplies such as rivers, lakes and impounded reservoirs. For example, the Metropolitan Water Board, which serves a population of nearly eight millions spread over an area of 570 square miles, at the overall rate (including industrial supplies) of 40 gallons per head per day, dispenses nearly 300 m.g.d., and at the culmination of the air raids on London, the losses by damage to mains and increased demands for fire-fighting brought this figure up to 360 m.g.d. Of the normal 300 m.g.d., about 15 per cent. to 17 per cent. comes from underground sources, mainly wells in the Lee valley area, South London and West Kent. The remaining 83 to 85 per cent. is obtained from the river Thames above Teddington and the river Lee, great storage reservoirs having been built to balance winter and summer flow. A certain amount of the water from springs in the Lee valley is brought direct to reservoirs in the city of London, at ' Riverhead,' in the East Central district, by means of a canal, the New River. This particular undertaking is of great historical interest, for it marks the earliest attempt to supply the Metropolis with pure water. In 1604, at the instance of Sir Hugh Myddleton, a scheme was introduced for bringing the water from Chad's well (the Chadwell Springs, near Hertford, St. Chad being the Saxon patron saint of water) : by 1613 the construction of the artificial cut, the New River, then 40 miles in length, was completed. The demand for pure water rapidly increased, with the result that other neighbouring springs, such as Emma's Well (Amwell Spring) were brought into service. Much later, in the nineteenth century, further demands necessitated the sinking of large wells, some close to the original springs and others in the Lee valley nearer to London, some of which deliver water into the New River. At the present time the New River also brings to London about 22 m.g.d. of water (except in dry seasons) taken from the river Lee at New Gauge, near Hertford. Further supplies of water from the river Lee are abstracted lower down the valley at the Enfield and Chingford intakes.

Water Finding

While the overground supplies which it is desired to exploit are visible and can be measured or estimated with fair accuracy, underground resources are hidden and must be discovered by technical means. These resources may lie near the surface, or at moderate depths up to, say, 800 feet, or they may be very deep—perhaps too deep for economic extraction. As noted in the foregoing paragraphs, the quantity of water available and the depth at which it occurs, as also the quality, depend on the nature and arrangement of the rocks. It is the geologists' function to study and advise on these questions, just as it is the engineers' to exploit the supplies when found. The geologist prepares maps showing the area occupied at the surface (i.e. the outcrops) of various geological formations and indicates their thicknesses and relationships—whether, for example, they are down-folded into basins, up-folded into domes, gently tilted or horizontal, and if fractured, with what results. The official government department, H.M. Geological Survey (Exhibition Road, South Kensington, S.W. 7), whose excellent work is not so widely known as it should be, publishes such maps of various parts of the country, on different scales, e.g. ¼ inch to the mile, 1 inch to 1 mile and 6 inches to 1 mile. Among its sub-departments is one concerned with the geology of water-supply. *Water-Supply Memoirs* on a county basis, which record wells, springs, etc., are also available to the public at small cost. The public can thus obtain valuable information about any area in which they are interested by buying maps and memoirs and, if necessary, applying to the Director for further information. For a detailed investigation of any

particular site, however, the time and work involved may necessitate the aid of a consulting geologist.

Here it may again be emphasised that problems of water-supply can have wider bearings than those suggested above. Water, like fire, is a good servant but a bad master, and an application of the principles of water-finding enables the geologist to avoid, or get rid of, unwanted water in the case of engineering undertakings such as tunnelling, foundations for bridges, roads and factories, the lay-out of aerodrome run-ways and so forth.

Geophysical Prospecting

In those areas where the geologist is unable to determine from surface indications the depth of the water-table, or where the solid rocks are obscured at the surface by a blanket of superficial deposits like glacial drift, he is nowadays able to call to his aid a valuable weapon furnished by the physicist. The modern science of applied geophysics enables us to determine within limits the nature and arrangement of rocks and minerals, including oil and water, in the unseen underground. Magnetic, electrical and gravity (i.e. density) methods are used to locate ore minerals, and seismic (i.e. artificial earthquake) and electrical methods to assist in finding petroleum. In investigations connected with water-finding, seismic methods have been used to determine the thickness of glacial drift, which is liable to vary greatly, and thus to locate the position of the surface of an aquifer; but chiefly the method employed is an electrical one, which serves to define the boundary between certain rocks of different type or the surface of saturation in an aquifer. This is possible because the resistance to the passage of electric currents in the earth's crust varies in different types of rocks such as clays, sands or sandstones, granite, etc.; moreover, it varies according to whether or not they are impregnated with either fresh or salt water. A geophysical survey of an area admits of several possible explanations; therefore, the geologists' collaboration is needed for its proper interpretation.

Water Divining

It may occur to the reader that this modern development of geophysical prospecting is somewhat akin to the ancient, but not abandoned, practice of water divining, or dowsing. Without being suspected of condemning what may not be explicable in the present state of knowledge, one may point out that water diviners have never yet justified their claims in any tests which have been arranged under scientific control, with their willing co-operation. Indeed, it is noteworthy that such tests have had extremely unfavourable results—far more so than the law of averages might lead one to expect (see, for example, A. S. E. Ackermann, letters to *The Times*, October 5, 11, 20, 1938; U.S. Geol. Survey, 'The Divining Rod,' 1917; and J. W. Gregory, Brit. Waterworks Assoc. Conference, 'Water Divining,' 1927).

In order that the dowser may succeed, it seems that the water must not lie too far from the surface, and that it must be in motion, for still water does not, it is said, give any reaction. Thus a limitation is placed upon the help he can afford. Usually he is employed for the purpose of finding small supplies such as are needed for houses or farms. There is no case on record of a major undertaking (for example, one requiring one m.g.d. or more) in which a dowser's services have been enlisted and proved successful. As large consumers usually desire to avoid superficial supplies, because of the liability to pollution and, indeed, often exclude them by lining wells and boreholes to a depth of 100 feet, the possibility of aid from a dowser is correspondingly lessened. As already noted, water is frequently obtained from depths of 300 to 800 feet: also, there may be (as Fig. 1 shows) more than one water-table beneath the surface, if aquifers and impervious strata alternate, the lower rather than the upper sources of supply being the object of search.

Public confidence in dowsing is hardly strengthened when it is claimed that not only water, but oil, various metals, coins, corpses and other lost objects can also be located, and that the contents of envelopes and the proportions of copper and zinc in brass can be predicted.

The survival of the practice of water divining is doubtless due to the fact that shallow supplies of water are normally abundant and widespread (for the water-table lies at no great depth in many districts), although, where superficial deposits are present, they may be irregular and elusive.

The Increasing Demand for Water

With the improvement in the standard of comfort, cleanliness, and public health, the consumption of water per head is steadily increasing. The growth of manufactures and the development of new types of industry, especially those involving chemical processes such as the manufacture of plastics), is also adding greatly to the demand. In rural districts and in towns where there is little manufacturing, the requirements are still satisfied, apart from stock or dairy farming, at 15 gallons per head per

day. In thirty of the largest towns and cities of Britain, however, the figure falls below 20 gallons in only one instance, and at the top of the list Bradford stands at 55, Plymouth at 48, and London at 40 gallons per head per day. These figures relate only to supplies from public undertakings—either municipal departments or water-companies. Many industries in addition obtain their own supplies from rivers or wells. In numerous American cities, the daily consumption has already reached 200 gallons or more per head. Indeed, in the Utopian days to which we all look forward, some of our towns may, like Salt Lake City for example, have their streets flanked by gutters with clear running water.

As it is, the increase in water-borne sanitation, the provision of baths, the installation of central heating and hot-water systems, and car-washing all raise the domestic consumption substantially ; and, now, the fitting of bedrooms with basins (*vide* advertisements, h. and c. and ev. mod. con.) adds to the burden of the harassed water-engineer. All these new developments lead not only to a greater use of water, but to a greater waste. For example, who among us, when hot water is on tap, does not run off much cold and warm water to waste, until the satisfying hot supply arrives ?

Rural Supplies and a Water Grid

The supply of water to rural areas raises special problems. Although some districts are adequately supplied from rivers or springs or by wells of moderate depth, others have been dependent on shallow wells and small springs to which there is the two-fold objection, first, the liability of the water to pollution (especially if the local sewage is dealt with by means of soakaways or even cess-pits) and, secondly, the tendency of the water-level to fall below that of the bottom of the well or outlet of springs during times of drought. Added to this there is sometimes the difficulty that water has to be transported for greater or less distance by hand or in carts. Obviously, a rural community is often unable to meet the cost of sinking deep wells or laying lengthy mains. A cogent example of the kind of financial problem that may arise has recently been given by a well-known water engineer. The cost of a Rural District scheme involved £20,000 for wells, machinery and a pumping station and £80,000 for 80 miles of mains, making a total of £100,000, towards which a 1*d.* rate contributed only £150 a year. Small wonder is it that when efforts have been made to promote a water scheme, they have been opposed by those whom they were intended to benefit. As with cheap postage, it would appear that the community as a whole must agree to subsidise rural areas, for rural health and well-being are at stake. If agricultural prosperity is to be assured after the war and home-produced food supplies, including milk, are to be maintained or increased, the problem is already urgent. It is therefore satisfactory to note that, at the time of writing, the Government's Bill to improve rural water supplies has passed both Houses of Parliament. The Bill provides for the allocation from State funds of £15,000,000 for England and Wales and £6,375,000 for Scotland, in aid of remedial measures ; which is a good beginning, although only a beginning. The Bill also provides for the improvement of rural sewerage and drainage, a necessary step if the danger of pollution of water supply is to be reduced. The provision of piped supplies to every house and farm in the kingdom is, of course, actually controlled only by considerations of cost ; there are no inherent engineering difficulties in such a complete scheme. However, the bringing of piped supplies to out-of-the-way hamlets, farms and cottages, desirable as it may be, must necessarily take much time, as well as involve much expense.

Proposals have been made from time to time to satisfy the requirements of rural districts where local wells are not sufficiently deep or productive, or streams and springs adequate in quality and quantity, by means of a ' water grid,' resembling the electricity grid. The outstanding difficulty here is the high cost of mains, which, as the figures cited above indicate, are expensive as compared with the cost of sinking wells and boreholes. Although the scheme in its broadest sense is impracticable on financial grounds, local grids would appear to be necessary in those districts which cannot, from their geological nature, be self-supporting. But the potentialities of every district should first be investigated and the resources fully exploited, before embarking on any expensive regional undertaking. Parliament safeguards the existing resources of country districts to this extent—that, when neighbouring large authorities promote schemes, the so-called legal canon is usually observed, to the effect that water-supplies should not be taken out of a district if there are reasonable grounds for thinking that they will be required in that district.

Water Supply and Post-war Planning

The suitability of land for various purposes included in the purview of planning depends on subsurface geological features.

In attempts to use these to the best advantage, the problem of reconciling conflicting claims will inevitably arise. In many cases, difficulties will be found to be inherent in the actual claims, e.g. concerning the use to which undeveloped land shall be put, apart entirely from the problems raised by particular vested interests. However, the geological characters of an area cannot be altered: and it so happens that those which render land suitable for residential purposes are just the characters desirable also for the maintenance of underground water-supplies. A difficulty at once arises, for houses, factories and made-up roads constitute an effective mackintosh, preventing the rain from sinking underground by diverting it to swell the surface drainage, i.e. the run-off. Reservation of land for agriculture or open spaces on the one hand and water-supply on the other need not, it is true, lead to conflict, but if schemes are contemplated, scientific advice should be taken in every case.

The provision of water for public domestic use and the ever-increasing needs of industry are often difficult to adjust. As mentioned already, certain large works now require as much water as a big town of 100,000 to 200,000 inhabitants: if the supplies are derived from underground sources, considerable areas of the country will thus be preoccupied; if from rivers, problems no less controversial are raised. The development of new industries after the War of 1914–18 made heavy demands upon water-supply and in many districts upset the balance as between public and private requirements. In connection with the establishment of new industries, it must be remembered that whilst certain raw materials can be economically carried, the transport of water in considerable bulk involves relatively large capital expenditure.

Much of the water required in industry is used for washing and cooling purposes (when supplies of a high degree of purity are unnecessary), and is released again as effluent, often but little polluted, but sometimes unusable until naturally purified by self-aeration in rivers or artificially purified before discharge from the works. Greater use could undoubtedly be made of 'second-class' water by industries in many districts. The manner and ease of disposal of effluents, so as to do the least harm to the community, are dependent, like the location of cemeteries, sewage works, and drainage operations generally, on the geological character of the country. Inland communities can, if they so wish (and are prepared to incur the expense), mitigate the difficulties of a restricted water-supply, by introducing a system which is in effect a minor cycle within the general rainfall cycle. To this end, sewage and works' effluents are purified and brought back into service as water-supply. An approach to this state of affairs is seen in the provision of a dual supply in some localities, one set of mains furnishing potable supplies and another set delivering water less thoroughly purified for washing and flushing. But among the objections to this practice are the high cost of a double set of mains, public prejudice, and the danger of the use of the wrong supply.

No doubt many people are familiar with the misfortunes, only too common, which have arisen from evacuation and billeting, the establishment of camps, and the building of houses and works before the essential water-supply has been assured. Engineers and geologists are frequently asked to find substantial supplies of water, not only for growing communities, but also for works which were planned, or even constructed, before adequate resources were proved, or where account had not been taken of the increased demands of expanding business. Such lack of foresight frequently accompanies haphazard growth, and is only to be expected in the absence of planning schemes.

Before industrial works are located, consideration is naturally given to questions such as proximity of markets, transport facilities, availability and cost of power, sources of raw materials, local supplies of labour and housing facilities. To these primary considerations there should always be added that of adequate water supply.

Water Purification and Softening

Great care is taken nowadays to ensure that water for domestic use is free from pollution. Gravity supplies from upland regions have usually a high degree of purity, and are soft, but being slightly acid tend to attack any lead pipes through which they may be transmitted. In that case, they must be treated for 'plumbo-solvency,' usually by the addition of hydrated lime, which also has the effect, in many people's opinion, of rendering the water more palatable. Any turbidity and colour (such as that due to peat) are removed by filtration through sand and chemical treatment. Special treatment (e.g. with copper sulphate or other chemicals) is sometimes necessary to stop plant growths in pipes or reservoirs, and much investigation is at present in progress on such growths and on lowly animal life found in reservoirs.

River water, when brought directly into supply and not stored in reservoirs (where it is often to some extent self-purifying), receives special attention. The care taken to de-

contaminate it may be indicated by mentioning the treatment now adopted in the case of a public supply from the river Chelmer and its tributaries. The water is first led into a sedimentation reservoir, where it is purified to some extent naturally ; then it is treated with sufficient lime not only to make it soft, but also to render it safe bacteriologically, after which the excess lime is removed by carbon dioxide. The water is further treated with carbon to remove any taste and, if necessary, chlorinated. It is also filtered through sand-filters.

Underground water is itself bacteriologically pure, but care has to be taken that pollution from the surface is not allowed to reach it. Should it be liable to such contamination it is appropriately treated nowadays, usually with small doses of chlorine or ozone. In the course of its passage through rocks water has often taken into solution some compounds of calcium (lime), magnesium, sodium, potassium, etc., and has acquired in consequence a greater or less degree of hardness. Hard waters with 250 or more parts of dissolved lime, etc., per million are found in districts underlain by limestone (including Chalk), where the river, lake and underground supplies all display this feature. Some water authorities go to considerable expense in order to soften the water, the common treatment being the addition of hydrated lime, which precipitates the chief hardening constituent, calcium carbonate (the 'fur' of kettles and boilers). Every housewife knows that, apart from discomfort in washing, the consumption of soap is enormously reduced if soft waters are used ; indeed, it is said that the saving in soap alone would far outweigh the cost of softening.

Water-softening apparatus, for domestic use as well as in works, is becoming increasingly popular. The principle underlying the treatment is that known as 'base exchange.' By the addition of chemical compounds of soda (permutites), allied to the natural minerals, zeolites, an exchange of lime from the water and soda from the permutite takes place. When the action of the permutite is exhausted, it can be revivified by treatment with a sodium compound such as salt.

Some waters, especially those which have come from considerable depth or from rocks of special types, may be enriched in certain constituents such as iron, magnesia, sulphur, or radio-active elements. Such medicinal springs and waters, many of which have been utilised since Roman times, are the foundation of the prosperity of the health resorts known as spas.

On the other hand, certain constituents, notably fluorine and molybdenum, have been found by recent medical investigation to have deleterious effects on animal life, even when present in only minute amounts. From fluorine, for example, there develops fluorosis, which attacks human teeth and causes other serious bodily derangements. Thus the necessity has now arisen for re-analysing all waters used for potable supplies, not merely as heretofore to determine their major dissolved constituents such as lime and soda, but also the minute traces of rare elements, some of which are beneficial and others harmful.

In connection with water purification, one recent advance must have stirred us profoundly, namely, the statement that methods have been devised for preparing drinking water from sea-water on a small scale suitable for use in boats by shipwrecked crews. Two types of apparatus, which work on rather different principles, have been devised —in Britain and America respectively. The British method is based on the belief that distillation is the most promising procedure. The Ministry of War Transport has therefore arranged to equip all ships' lifeboats with stills, worked by solid fuel or paraffin, each of which yields about ½ gallon of fresh water an hour. The American type is based on the treatment of sea-water with chemicals in plastic processing bags, each apparatus furnishing ½ to ¾ gallon an hour. A chemical compound which removes chlorides is added to an upper bag of sea-water, and the bag is kneaded ; the water is then transferred to a lower bag, where another chemical substance is added in order to remove soda, and the bag is well squeezed, the resulting fresh water being drawn off by means of a tube.

Conclusion

It is common knowledge that the subject of water-supply is far reaching and has many repercussions. In the space here available many aspects of the subject have necessarily been treated in a somewhat sketchy manner ; and reference to others has perforce been omitted. For further information concerning many of the subjects here dealt with, and on other topics such as British water-bearing formations, and the source of supplies for particular towns and districts, reference may be made to R. C. S. Walters's volume *The Nation's Water Supply*, Ivor Nicholson and Watson, London, 1936, and to the publications on Water-Supply by H.M. Geological Survey.

ANTHROPOLOGY:

The Science of the Study of Man

By Mrs. Hingston Quiggin and Professor J. H. Hutton

Introductory

Anthropology—the scientific study of Man—is ultimately the most important of all the sciences concerned with social and international relations, for wherever and whenever science is studied and whatever the science may be, Man is inevitably the student and our sole interpreter. So the study of Man himself, what he is and how he came to be so, his physical and mental evolution, the extent to which his body and mind alike are influenced by heredity or environment, his varied social relationships in primitive and in civilised communities, their origins, development, motives, interactions and results—problems such as these, of urgent significance at the present time, belong to the domain of anthropology. As a modern science anthropology was a late starter, for although theories of evolution were prevalent before the time of Darwin, they were insecurely founded, lacking the support of observed facts, which he was among the first to provide. As long as Man was content to consider himself a special creation made in the image of God and deposited in the Garden of Eden in the year 4004 B.C. (a conception not yet entirely discarded) he remained outside the realm of science. During the earlier half of the nineteenth century interest in native races was not lacking, and a practical outlet was provided by the Anti-Slavery movement; but Man scarcely took his place in the world of Nature as a fit and proper subject like all other animals for scientific study, before Darwin's *Origin of Species*, published in 1859, had secured general acceptance. Indeed the range of geographical knowledge had been too limited, and it was not until the races of the whole inhabited globe had been brought within the scope of observation that the necessary material became available. This condition was unfulfilled until the nineteenth century explorations of Arabia, Central Asia and Central Africa had more or less completed our knowledge of the earth's surface.

The tardy recognition of anthropology as a science and its uncertain position among the sciences are illustrated in the *Reports* of the meetings of the British Association from 1833 onward. Papers on anthropological topics were at first included in Zoology and Botany, or in Medical Science; after 1851 they appear in the section Ethnology and Geography, with an occasional excursion into Biology. In 1871 Anthropology was given a separate 'department' in Biology, and in 1884 (under E. B. Tylor at the Meeting at Montreal) finally promoted to the dignity of an independent section.

This uncertainty in scientific association is itself significant, for anthropology, more than any other science, invites co-operation. It includes ethnology (the comparative study of races) with which it is often confused; it is dependent on zoology and anatomy, physiology and psychology, archæology (with geology) and palæontology; it embraces technology and folklore; and it is inseparably linked with comparative religion and with linguistics—and it humanises them all. None of these can be entirely ignored in making a comprehensive study, and each contributes in some measure to the two main areas of anthropological research, the *physical* and the *cultural*, centred respectively round *race* and *environment*, the double influences continually moulding the life of Man.

But there is one characteristic which differentiates anthropology from most if not all other sciences. The scientist *per se* is concerned solely with the observance of facts and the deductions therefrom. He may criticise but he is not really concerned with moral values, nor is he the arbiter in questions of 'good' or 'bad,' of right or wrong. Nevertheless, since the material in which he works is Man himself, it is impossible for the anthropologist to be insensible of the ethical aspect of his problems, he cannot dissect or analyse his material with the aloofness that a chemist can maintain in a laboratory, since that material is himself. Far from forgetting the fact that his researches may have definite and permanent effect on the welfare of the human race, he is aware that that welfare constitutes the justification of his researches. The impulses stimulating anthropological research were in their origin largely humanitarian. It was the sympathy evoked by the inhumanity of the slave trade and a desire to raise the status of the Negroes and other oppressed races that laid the foundation of what was first the Ethnological Society (1848) and is now the Royal Anthropological Institute; similar sympathies and similar desires have continued to animate the

work of the anthropologist in all parts of the globe.

A brief survey of what anthropology has done, is doing and can yet do, to throw light on human problems, past, present and future, will indicate its vital interests in international and social life.

Physical anthropology forms the bedrock of study and underlies all understanding of the nature of Man, for from his physiological functioning spring all his intellectual, æsthetic and social activities. Man must first, therefore, be studied objectively, body and mind, and his past history explored, to discover his origins, to trace his ancestry and to determine his position in the animal world.

Physical Anthropology

The physical features of Man, their variation and their contrasts, are obviously the first to attract attention. Over three thousand years ago the Egyptians painted the walls of royal tombs with representations of the four contrasting types then known to them, the red sunburnt Egyptians, the yellow Semites, the black Negroes and the white Libyans with blue eyes. Similarly Assyrian, Persian, Indian, and Maya sculptures, Bushman paintings, African carvings, or the drawings of Melanesian children, all show the work of untrained but not unobservant ethnologists. The material has long been with us, supplied by travellers abroad or observers at home ; the scientific study of it is a recent development. Its first serious student in England was J. C. Pritchard, a doctor who found ample material and entertainment in the Bristol docks. His *History of Man* appeared a few years before Darwin's *Origin of Species*. With the new light shed on Man's origin and Man's place in nature by such scientific workers as Charles Darwin and Thomas H. Huxley, together with the accumulation of evidence collected by explorers, travellers, missionaries and administrators, various attempts were made to construct a satisfactory scheme of race classification based on the colour of the skin, the shape of the head, the character of the hair, nose, lips and other physical features : and attempt was made to isolate ethnic types and to map out their distribution. Language was here called in to assist, and many of the so-called ethnological maps would now be more accurately described as linguistic. As material accumulated there was a fine field for statistical tabulation. Cephalic, nasal, and orbital indices, stature and length of bones were plotted in series and reduced to mathematical formulæ, and a 'race' was identified on the measurements of some score—or less—of skulls of doubtful sex. The pendulum has now swung far in the opposite direction, and there is a tendency to regard much of this mathematical elaboration as wasted effort. Measurements of less than a hundred individuals are regarded as of little value, and although anthropologists are not united in their interpretation of the word *race*, few, if any, recognise the existence of a 'pure race' at the present day. Nevertheless the 'pure race' theory has coloured history and embittered wars. After the Franco-Prussian War the French ethnologists detected the mainspring of Prussian atrocities in the fact that they were not Teutons, but alien intruders into Europe, hence barbarians, determined to destroy a culture that they could not appreciate. The German anthropologists retorted in practical and ingenious fashion with a census of the hair and eye colour of six million school children, to prove (if statistics of immature colouring thus collected prove anything) that Prussian children were as fair, or almost as fair, as their neighbours to the west. The war of 1914–18 provided an opportunity for checking juvenile pigmentation by measurements of head form of prisoners of war with interesting results. For although fair hair and light eyes predominate in Germany, especially in the west, the shape of the head (with an average cephalic index of 82, rarely narrowing below 80) betrays its non-Nordic character. We are only too well aware how distorted theories of race have aggravated the more recent war. The German obsession as to Nordic superiority and as to the Nordic character of the German nation has been responsible for the most hideous crimes against humanity that the so-called civilised world has ever witnessed. And it has no scientific justification. The true Nordic type, tall, fair, blue-eyed and long-headed (prone perhaps to tuberculosis and drunkenness no less than to a life of adventure) is almost confined in Germany to Friesland and part of Saxony, and the superior moral and mental characteristics which German theorists have associated with it are apparently no more widely spread in Germany than the physical type itself. The prevalence of homicide, suicide and illegitimate births (twice and thrice that in England) would seem to indicate decadence rather than supermanhood. Such distorted theories paraded as scientific, are attempts to pervert science to serve political ends.

Another perversion has supported the 'colour bar.' The belief that the black-skinned races were black on account of the sin of their ancestor Ham who saw the nakedness of his father Noah (Genesis ix) who cursed him, or even that they were a

separate creation, destined by Providence for servitude to the whites, was a convenient justification for their exploitation down to the nineteenth century. The belief was maintained by men of science as well as by politicians, and was supported by some members of the British Association as late as 1863. Even some of those who accepted the Darwinian hypothesis of descent from an ape-like ancestor postulated separate ancestors for white and black races, and claimed that the negro was more closely related to the ape than to the white man, although the facts of interbreeding demonstrate the absurdity of such a hypothesis. Anthropologists of the present day are generally agreed upon the essential unity of the human species and upon the absence of innate superiority and inferiority, though final proofs of this are not easy to point out. Much work has been done, especially in America, in attempts to correlate race and intelligence, but so far without definite result. Any differences discernible appear to be due to culture and to social and geographical environment rather than to ancestry. But though anthropology lends no support, the ' colour bar ' still persists, a relic of unscientific prejudice fostered by economic fears, to embitter social and international relations.

Anthropology has rendered services to mankind by exposing the unscientific character of the theories underlying the ' pure race ' and the ' colour bar ' prejudices. It also combats the racial or social antipathies based on other prejudiced sentiments such as those underlying anti-Semitism or class warfare. It teaches tolerance, showing men that there are other ways of life as good as, if not better than, their own. By its researches into human history it has helped to place man in his proper setting and his proper perspective, and by tracing his evolution from humble origins in the past, may give some indication of possible development in the future.

At first sight the mere statistics of the various parts of the body, including the brain, with which physical anthropology is mainly concerned, may not appear important in contributing to the solution of present-day problems. But upon such statistics depends our knowledge of the average heights, weights, proportions, corporal and mental capacity of individuals, of groups and of communities, thus providing means for estimating physical fitness, and for measuring advance or retrogression. Such statistics may have practical economic value. There was a clear example of this in Italy in the early days of conscription for the national army, which was modelled on the admired efficiency together with the physical measurements of the Prussians. It was found that an unexpected percentage of A1 men were being rejected in some areas though not in others, and this led to an inquiry and ultimately to an anthropological survey of the whole country, revealing the marked but unsuspected contrasts between north and south. In more recent times it has been pointed out that had the survey of militiamen, advocated by the Anthropological Institute been carried out, valuable information would have been obtained for the benefit of designers of military equipment. Such surveys have wider uses. They supply the materials necessary for distinguishing the good and bad effects of race-crossings and hybridisation, for analysing the movements of peoples, as well as for attacks on such immediately urgent problems as under-nutrition, the effects of alteration in food supplies, and susceptibility to disease. Unless some acceptable standard can be established by means of reliable statistics—and the standard will vary from area to area according to the varying racial stocks from which the inhabitants are derived—inquiries as to under-feeding, over-feeding, or injudicious feeding lack a scientific basis for comparisons. In our own country a keen interest in diet has been aroused by restrictions due to the war, and the doubts that have been raised as to its sufficiency for building up healthy school children or providing the nutriment required by heavy workers indicate that research is of prime importance if we are to maintain efficiency in the post-war world. It is particularly in its biological approach that physical anthropology has been expanding recently ; and work on such questions as pigmentation, excess or deficiency of minerals such as manganese, iron or iodine salts, and the effects of variations in sex ratio, on sex-linked factors of inheritance, genetics and so forth, seems likely to prove of increasing significance.

Of particular importance have been studies of inheritance and genetics (based on the re-discovery of Mendel's laws in 1900) and research on blood-grouping. The story of Mendelism is well known, and Mendel's pairs of tall or dwarf peas, yellow or green, round or wrinkled, with dominants or recessives occurring in regular proportions in successive generations, gave the clue to inheritance in man, and it was observed that while peculiarities such as albinism or brachydactyly (having fingers short of a joint) were recessive characters, and other exceptional features such as colour blindness or hæmophilia were sex-linked recessives, even stature, pigmentation, and eye colour probably occur in accordance with the Mendelian formula. More recent work on chromosomes and sex-linked factors as well as investigation into

hormones and the influence of glands indicate ways in which physical anthropology may help to throw light on the composition of Man.

The wartime need for satisfactory methods of blood transfusion has probably stimulated research into the question of blood groups, the agglutinating factors of which are inherited on Mendelian principles. The Chinese apparently were using a crude form of blood test for paternity more than 100 years ago, but without precise knowledge of the nature or implications of what they were doing. In Europe the varying properties of blood groups were discovered independently towards the end of last century, when it was noticed that the blood of certain individuals caused clotting when transfused into the veins of others. The different types of blood were classified as O, A, B and AB according to their content of the clotting character. This is of the first importance in the case of blood donors for hospital work. The distinction is also significant in racial discrimination and distribution. Group O which is innocent of agglutinating qualities appears to be the most widely distributed and is probably the most primitive. The A and B groups, commonest in Europe, are non-co-operative, B possibly representing a recent intrusive factor. It is unlikely that blood grouping can ever be used, as was at one time hoped, to sort out the races of man, but it is certain that it can provide valuable evidence in the case of hybridisation, as of paternity, and its definite hereditary character makes it a useful check on hypotheses of racial affinity.

The Darwinian hypothesis laid the foundations of the scientific study of anthropology ; but it was the antiquaries who did the spadework, digging laboriously for the evidence of man's forerunners ; and by their industry during the last century, skeletal remains of early man gradually came to light, and were fitted in here and there into the scheme of human evolution. Flint tools of immeasurable antiquity had been discovered in the eighteenth century, a puzzle to archæologists who retained the Mosaic chronology, which limited the existence of man to a few thousand years ; and as fossil human bones accumulated in France, Belgium, Germany and other parts of the continent as well as in England, associated with the remains of prehistoric animals, the belief that they belonged to the dim and chaotic period before the Flood became no longer tenable. Human history was thus pushed back for thousands of years, and anthropology began to grope back in tens or even hundreds of thousands of years before the Christian era. Java Man and Neanderthal Man were claimed as ' missing links ' in the search for our ancestors, and the belief gradually gained adherents that *Homo sapiens* was, as Huxley insisted, rather a ' perfected monkey ' than a ' degenerate Adam.' Though finds of human fossils are still rare, many other claimants have since come to light to provide new and unexpected problems, and no palæontologist would now suggest that man's family tree (less often found in textbooks than was formerly the case) was more than a conjectural sketch. Piltdown Man in England, Pekin Man in China, Rhodesian Man in Africa, and many others, have complicated rather than simplified the problem, and the nature and causes of human evolution and variations await further evidence.

Psychology

Turning from the scanty relics of extinct species of man to the examination of the physical and mental functions of living races, we come up at once against psychological problems. Psychology proper is no doubt a different discipline and cannot be treated here. At the same time, anthropology cannot ignore psychology since it is vital to its science ; profoundly associated with physiology as it is, it forms a bridge, as it were, between the physical and cultural sides, and a link not only with psychology proper but with medicine, sociology, education and even economics. Some measure of it is indispensible to a broad view of anthropology in relation to human activity. Up to date, however, not a great deal of scientific work in this direction has been done. The Cambridge Expedition to the Torres Straits in 1898 was the first to include trained psychologists, and some attempts were made to collect records of the sensory and mental efficiency of a group of islanders to be compared with experiments made on other peoples, civilised and uncivilised. It was important to know how far the sensory perceptions of uncivilised man, his sight, taste, smell, reactions to pain, etc., differed, if at all, from those of civilised man, and to discover, if possible, why he sometimes appears to think in a different way.

Psychology is also needed to contribute to the study of the effects of climate and environmental conditions generally upon the behaviour of the group ; of the peculiar suitability of any given group (if indeed there be, as there seems to be, some such suitability or adaptability) to some particular form of activity or the use of particular skills ; and of the mental and intellectual proclivities of the group. It will be increasingly important in the future to determine the effects on population of alteration in their environment, of changes caused by the development

of natural or economic resources, or by the introduction of increased means of transport or communication. It may prove of practical value to be able to estimate the aptitudes of a given population for different pursuits, their intellectual or artistic capabilities, or their reactions to the trends and stresses of their social structure. Problems of mass-psychology and of large-scale behaviour come within the scope of anthropology, and any light that can be shed on them is urgently needed in the work of pacification and reconstruction that lies ahead.

Cultural Anthropology

This branch of the subject may be subdivided into (*a*) *material*, and (*b*) *social*. It studies on the one hand material culture—the whole material environment of man, his handiwork past (archæology) and present (technology). On the other hand it is mainly concerned with his occupations and daily life, and with his social structure, how it has developed and how it works in practice; and it includes in its survey the influences of language and tradition, religion and folk-lore. It attempts to discover how and why human beings contrive to live successfully together, and, incidentally, by noting mistakes and misfits in the past, may suggest guidance for the future. The prehistorical background which throws light on our own past as well as sidelights on primitive societies in general is provided by the archæologist; and the successive stages of the Stone (Palæolithic to Neolithic), Bronze and Iron Ages envisaged by Lucretius before 55 B.C., confirmed by Thomsen barely a century ago, are now sufficiently familiar to figure in cross-word puzzles in the daily press. Dr. Johnson asserted 'We *can* know no more than old historians have told us.' To-day, on the evidence of tool or potsherd, archæologists can reconstruct the history of thousands of years ago more surely and scientifically than by means of any of the 'old historians.' Excavations in Palestine and Mesopotamia confirm or confute, illustrate and illuminate the stories in the Old Testament; in Greece and Crete, those of Homer; in Asia Minor and the Near East, those of Herodotus; and in Egypt, those of ancient records; while in these and in other parts of the world vanished empires, forgotten kings and conquerors and facts utterly unknown to history are constantly being brought to light. Moreover, by providing a time-scale, the early remains of man can be placed in their proper sequence and their historical setting, by means of his tools, weapons or pottery, or the animals or grain on which he fed.

Technology carries on where archæology leaves off in the study of the handiwork of man. Between them they reveal the fascinating stories of the origin and distribution of such crafts as pottery-making, boat-building or weaving, or trace the evolution and migrations of such things as battle-axes and boomerangs, or the spread of the use of tobacco or of cowries. And here a word may be said for museums, often doubtless dusty storehouses of lumber, but when intelligently arranged and intelligently visited (perhaps under discreet guidance) affording an unrivalled means of education, enlarging the interests of intelligent adults while appealing especially to the curious child.

The British were the first in the field in many parts of the world; we are still in charge of more outlying and backward regions than any other nation, so our opportunities for representative collections are unsurpassed. Yet their demonstration leaves much to be desired. There can be no doubt that exhibitions of the arts and crafts of the past may act as stimuli to better craftsmanship in the future. The revival of native carving or pottery, basket-work or weaving, in those parts of Africa, America, or Oceania where the influence of trade goods has corrupted or ousted local effort, depends largely on what has been preserved in museums (and so in some measure, makes amends for spoliation in the past). Moreover, it is wholesome for 'civilised' workers to see how, in many respects, such, for instance, as Peruvian textiles, Malayan or Californian basketry, African grass-cloth, Indian metal-work or Chinese pottery, modern work falls far short of the less 'civilised.' No one who has visited the magnificent and munificently endowed museums of the Continent or America can fail to be enthralled; no one who has visited the local museums such as the Oslo Museum in Norway, the Peace Museum in Zanzibar or the Maori Museum at Hobart, can fail to see how they stimulate proper local pride; and no one can visit any museum without recognising the fundamental unity in diversity of man's interests and his handiwork.

The study of material culture, however, cannot rest content with merely discovering or preserving the past; it has much to do with the present and with the future. It is doubtless simpler to reconstruct the technique of the inventions of boat-building, textiles or pottery than to estimate their social effects, but it is within the range of the anthropologist to note the effects of recent inventions such as railways or wireless telegraphy on man, either in the mass or in smaller units. Perhaps the most practical application of this study is that of the impact of a

mechanised civilisation on peoples of less developed culture; of the effects, for example, of the introduction of matches and firearms, of trade goods or of currency, on local industrial, economic or social life. And here technology links up both with psychology and with social anthropology.

Social anthropology is as old as society itself. The queer habits of their neighbours doubtless provided material for gossip in the early ages of man. But the scientific study of habits and customs is a recent development, and its importance in connection with modern problems is obvious. The science of social anthropology not only interests itself in all the varieties of human habits and customs, behaviours and beliefs; it attempts to analyse the import of these to those who practise or possess them, and to estimate their significance to the community. In the earlier years emphasis was laid on universal theories, whether the individual, the family or the community is the more primitive unit of society, the relative seniority of father-right or mother-right, or the evolution of marriage. Such generalisations were often based on slender evidence and hence the demand for more, wider and yet more intensive fieldwork. And the nature of the fields has also altered. In the past the more primitive or savage societies were studied with a view to discovering the 'primitive' characters of social structure. The more modern trend is to study societies in transition, to discover what features resist innovation and which persist, thus indicating what makes for cohesion and what is destructive to the social life. With modern methods of transport the world is rapidly shrinking in size so that no portion of it is beyond the reach of social disintegration by means of the trader, the administrator or the missionary, and it is of vital importance to know whether the impact will be for good or for ill, whether it will lead to advance or deterioration, and how far alterations in social structure can be controlled for the benefit of the community concerned.

Governments at home and administrators abroad are becoming increasingly aware of the importance of some training in social anthropology, if only as a means of avoiding such serious and expensive measures as have resulted from ignorance in the past. Perhaps the best known example is the Ashanti War of 1900, involving over 1,000 casualties which a little anthropological knowledge might have easily averted. If we look back to 1855 it is easy now to see that the Santal rebellion in India might have been avoided by the same means. A further example may be taken from Southern Kordofan. The official who dealt with the Nuba used to camp at the foot of their hill and send for their chief. The chief was a rainmaker who must never leave the hill-top. So the tribe was faced with the dilemma of disobeying the order for his appearance, or the loss of his supernatural powers. When they chose the former course, risking mundane rather than spiritual vengeance, they brought disaster on themselves and serious trouble and expense to their rulers. Many examples might be quoted to show how even a little learning might have averted catastrophes.

The general policy throughout the British Empire is 'to uphold the indigenous culture of the subject race except where it conflicts with the moral and social ideals of the governing people'—in plainer language, to quote Mary Kingsley, 'unless it is too blood-stained for an English gentleman to handle.' This policy is impracticable unless there has been sympathetic study of the particular 'subject race.' How are such indigenous customs as cannibalism, head-hunting, the vendetta, or local forays to be dealt with satisfactorily without knowledge of their significance in native life? Mere prohibition often does as much harm as good, driving violent forces underground. But with sympathetic understanding and a little ingenuity pigs can be substituted for human victims (as in Papua); skulls can be systematically lent out for ceremonial purposes (as in Sarawak); or tugs of war instituted in place of intervillage fighting (as in New Guinea). Methods of this kind are nothing new. Amasis, king of Lower Egypt in 550 B.C., substituted wax figures for the human victims sacrificed daily at the temple of Ammon. And to-day in the Naga Hills wooden figures of the stems of plantain trees are substituted when social convention requires the adolescent to attest his maturity and reinforce his manhood by killing an enemy. Another problem which gives trouble in many places is that of sorcery, which influences the lives of all members of the community, particularly in certain African and Melanesian societies. Should it be recognised and sternly stamped out, or should it be ignored? A death occurs, due possibly to poison but perhaps merely to suggestion, and in either case there is rarely any evidence for conviction. The relatives of the murdered man call for vengeance on the sorcerer, and, failing legal assistance, may kill him themselves in the (sometimes) justifiable belief that they are meritoriously ridding society of a dangerous criminal. Witches are often convinced of their own powers and plead guilty to causing death by actions which can only be symbolic. Even a Christian convert has been known to confess responsibility for the depredations of a

leopard into which he believed himself to be in the habit of projecting himself, albeit unwillingly enough, night after night. Only a knowledge of the indigenous beliefs about magic, death, and justice will help to make it possible to fit a punishment to the crime which will satisfy law-giver and native alike. How, again, without knowledge, can one deal satisfactorily with a case like that of Kuki of Bolbung who complained against his chief for causing his wife to miscarry. The husband had been given a well-earned thrashing in one village when his wife happened to be *enciente* in a more distant one. The chief nevertheless admitted the miscarriage as being caused by the thrashing, though denying (with doubtful truth) knowledge of the wife's condition.

Since the first duty of government is to enforce law and order, it is important to know what law means in native estimation and how it is locally enforced. It is not sufficient to place a chief in authority in a district, giving him insignia and a pension. Unless his authority is recognised by the people over whom he is placed, disorder will follow. Indirect rule is the term applied to a policy by which the supreme government recognises indigenous institutions and organisations and makes them its agents in administration and legislation. The system was not invented by anthropologists. It was prophetically characterised when in 1862 Moshesh, chief of the Basuto, wrote to Queen Victoria (describing himself and his people as 'lice under her blanket') : 'My people will be her subjects, but under me—I wish to govern my people by native law, by our own laws ; but if the Queen wish after this to introduce other laws into my country, I would be willing, but I should wish such laws to be submitted to the Council of the Basuto.' Basutoland has been governed on those lines ever since. Indirect Rule is the policy of government in such regions as the Gold Coast, Nigeria, Uganda and Tanganyika Territory in Africa, and in the Federated Malay States in Asia, and it is easy to see how anthropological research can affect its success. In some areas, as in Basutoland, and to a less extent in Nigeria and (though encountering more difficulties) in Uganda, the policy developed naturally from the conditions already in existence. But in many of the areas in which we have been called upon to undertake the government, especially in those handed over by mandate after the 1914–18 war, native institutions had been intentionally broken down and often obliterated, and it needed much investigation and patient research to discover and, if possible, restore or re-establish the organisation of tribal chiefs, clan councils, or headmen, and to define their powers. This has been the process carried out in the Cameroons, Togoland and Tanganyika Territory. And the matter is not as simple as it might seem. In the Northern Territories of the Gold Coast, for example, three different grades of chiefs were simultaneously in existence. There were the indigenous chiefs or priest-kings, whose authority was derived from supernatural powers, to whom were referred all matters that were too hard for the village elders to settle. Imposed upon these were invaders from the north, who made themselves rulers of the land, though without altogether supplanting the priest-kings, who still exercised their religious functions. With the advent of foreigners in recent times quite another class of chief was evolved in the form of some African, often a slave or bastard, who was pushed forward by the ruling powers to confront the strangers, take their orders, meet their demands, and possibly bear the brunt of their anger. When such as these are recognised as chiefs and given official authority over the real authorities in the district, the trouble begins. This is the kind of tangle in which the assistance of anthropology is valuable, illustrating the claim made for the science some sixty years ago : 'It is a knowledge upon which the happiness and prosperity, or the reverse, of millions of our fellow creatures may depend' (W. H. Flower, *J.A.I.* 1884). The policy of Indirect Rule has been criticised on the grounds that it is an attempt (encouraged by the anthropologists) to preserve archaic forms of society, to obstruct advance, to 'keep the native in his place,' and to deny him the benefits of our civilisation. But this is not the aim of the anthropologist, nor of anyone with common sense. Progress cannot be arrested. Only in such remote islands, as, for example, the Solomons down to last century, could customs remain uninfluenced from outside, but it is the manifest duty of new rulers to see that any changes for which they are responsible do as little damage as possible to native society. The damage that has been done to the detribalised native in Africa is patent to all, and no refurbishing of his past can repair the harm done ; but measures must be taken to prevent such degradation from becoming universal, and where it has already occurred, to check further deterioration.

A fertile source of misunderstanding and discontent is to be found in newly introduced methods of judicial procedure. One of the chief causes of dissatisfaction, disaffection and resentment against Europeans among the Bantu peoples of Southern Africa has been the treatment of natives in magistrates' courts, where formal pleadings are a stum-

bling block to the native not allowed to tell his own (no doubt largely irrelevant) story in his own way. Judges and magistrates are perhaps not conversant with native languages and depend on interpreters, often venal as well as ignorant themselves. Summary disposals are often not understood—a Witwatersrand magistrate has been reported to have disposed of five hundred native cases on one day. In the opposite category to summary disposal come complicated modes of procedure and a too technical law of evidence which makes any resort to courts of law very costly. In addition to this, (as Elwin has pointed out in the case of the Baiga, and Roy in that of the Munda tribe), a tribesman may be subjected to the influence of all sorts of chicanery by dishonest legal advisers, and learn for the first time that truth is a commodity which can be bought and sold. The result is apt to be that if he becomes involved in any sort of litigation he is liable to be ruined morally as well as economically. Courts are often distant as well as alien in type, and Elwin quotes the case of a Gond or Baiga plaintiff in Central India who walked 3,200 miles for the hearing of one case. The law, when applied, often does not agree with tribal custom, and the unfortunate tribesman suffers from a sense of frustration and dismay. The insistence on precise rules of evidence and procedure, and the refusal to listen to irrelevant matter (often less irrelevant psychologically) are particularly apt to disturb and upset the simple man who wants to get his story across, and is naturally impatient of the (to him) stupid rules which require proof of what everyone knows. For what is done in a small village of wattle houses, where no one has much privacy, is likely to be known to all its inhabitants, though it may be very difficult to get them to repeat it under oath. Indeed, an oath by its very nature may be a stumbling block in itself, for it consists in the use of a form of words committing the swearer to some terrible consequence if he speak falsely. It may therefore become operative as the result of an accidental and quite unimportant inaccuracy, or even entail the consequences foreshadowed as the result of falsehood, merely as the sequel to mentioning them, a point of view which sometimes leads the Naga of Assam to suffer serious economic loss rather than risk the possible dangers and consequences of swearing to facts which he knows to be true.

The treatment of land is another common source of trouble. One of the chief grievances of the Bantu of South Africa has been the Natives Land Act of 1913, which led to many evictions of natives from their farms. In a different way in India the Munda tribal chief, who had a right to certain supplies in kind, given occasionally, alienated these rather vague rights to foreigners, who tried to convert them into a regular money payment. This led to tribal disturbances and to the introduction of British courts and British police. The British courts interpreted the payments as rents and then interpreted rent as implying ownership, and by granting decrees deprived the real owners of the land of possession in favour of the holders of what were really vague rights to irregular provision in kind which the chief had probably no real right to alienate. The same story can also be told of other parts of India. In the case of the Santal tribe, much of their land was filched from them by the process of loans, often for seed, at preposterous rates which made the debtor a slave of the money-lender. One case is quoted of a debt of Rs. 25 at 75 per cent. per annum, cancelled thirty years later in the time of the debtor's grandson, after three generations of free labour. The actual land system of many primitive peoples is often so entirely different from that known to Europe that, unless sympathetically studied and carefully interpreted, much injustice can be done in perfect good faith by courts of law.

Very often the introduction of a currency and of communications with the outside world, which give access to some new labour market, have profoundly disturbed the life of more or less isolated communities. In such cases a new class of individuals, often little respected for their intrinsic merits, have left their homes and returned later, rich in cash and therefore in a purchasing power not possessed by their fellow villagers, whose social order is overturned by the monied *parvenu*. Such a society will no doubt adjust itself in time, but it is of great assistance if the nature of the disturbance from which it suffers is clearly understood from the start, if possible foreseen, and, as far as may be, forestalled. For a common result is the concentration of wealth in the hands of a few individuals, and ultimately loss of land, which goes either to a wealthy few or to the stranger or foreign money-lender. The land-owning cultivator is reduced to a landless labourer, and both land and labourer suffer from exploitation.

In the matter of forests, laws against the taking of forest produce, against clearing forests for cultivation, against hunting game and so forth, may, although framed for native benefit, operate most oppressively. The prevention of indiscriminate clearing and burning may be necessary in the interests of the country as a whole, and the control of hunting may be necessary in the interests of the forest dwellers themselves when the introduction of firearms alters the whole aspect of

hunting; but a thorough understanding of the economy as well as of the point of view of the local inhabitants is essential towards reconciling them to inevitable changes.

Another important question is that of indentured labour, which may aggravate some of the effects of the introduction of a money standard. Young and vigorous men may be taken away from the life of the community to work in mines, as in Africa, with the effect of reducing the number of males at the reproductive period, thus compelling females at the same time to work much harder, and effectively reducing both the land under efficient cultivation, and the reproduction of a healthy population. Actual depletion of the population by 'blackbirding,' such as was once practised in the Pacific, was of course more drastic still in this direction. There are other effects, however, such as changes in the age of marriage, in the status of wives, and in the general aspect of family life, which may follow the use of indentured labour on any considerable scale. Actual forced labour, the *corvée*, under which labour may be required as a duty to the state, though often necessary in some degree in areas without communications, can likewise become most oppressive, particularly when a country is opened up to numbers of minor officials—revenue, police, education, survey, forests, medical, veterinary, etc.—who may require transport at seasons inconvenient to the local inhabitants, such as harvest or other agricultural crises. Instances could be given of areas whose population had been depleted by excessive demands of this kind over a long period of time, and it is noticeable how, in parts of Africa where forced labour is customary, the villages are no longer clustered along the trade routes but isolated in the bush.

Excise is another subject in which some expert acquaintance with the habits and nutritional needs of primitive peoples is required. The importance for instance, of home-brewed liquor as a source of vitamins for the peasantry of India has recently been recognised. Alcohol may serve to some extent as a substitute for sugar where this is unobtainable. Excise monopolies, however, tend to substitute spirits for fermented liquor, and thus to replace what is really a food by what is merely a stimulant, with deleterious effects. Opium, again, generally a drug, is in some submontane climates almost a necessity; control is essential, but wrongly used tends to promote adulteration, surreptitious sale, smuggling, and the substitute of still worse drugs such as *ganja*. Where the monopolist is a foreigner and therefore impervious to local public opinion abuses in the opium trade are rife.

Diseases are inevitably introduced as a result of external contacts, and people who have developed no degree of immunity in regard to certain epidemics which in Europe are comparatively mild, often suffer to a devastating extent from measles and chickenpox, to say nothing of smallpox and venereal disease. Whole islands have been depopulated from such causes in the Pacific, and the Andamanese have decreased, on an average, by more than a quarter of their population every ten years or so since 1858. In that year they numbered nearly 5,000. In 1931 they numbered 460, including hybrids. No return has been published for 1941.

Firearms are no less deadly than disease, and in more ways than one. When the Maori first acquired muskets they started exterminating each other at a rapid rate; while an Eskimo settlement in the Arctic circle that was provided with guns and ammunition by the crew of a whaler was found later to have died out, apparently as the result of having killed off the local food animals so recklessly that it was left without food or fuel for the winter.

It will be obvious, then, that in legislation no less than in administration anthropological knowledge is necessary if social *malaise* is to be avoided or at any rate palliated. The majority of problems that arise in the administration of areas where life is primitive and backward are caused by troubles over food, over land, or over women; and knowledge of the daily needs of life, of the intricacies of land-tenure, of inheritance, of betrothal or of marriage obligations may steer a way through a mass of litigious obstruction. Social anthropology provides some of the clues which can not only help to solve the problems but can convert resentful obstructionists into helpful co-operators. Its aid has been acknowledged in the encouragement given by Government to anthropological research, and by the appointment of Government anthropologists in such areas as Nigeria and the Gold Coast in West Africa, Kenya and Tanganyika Territory in East Africa, in the Sudan, in Australia and in Papua.

Training in social anthropology is no less important for the missionary than for the legislator and administrator, enabling him to sift the wheat from the chaff, and to detect the moral values latent in heathenism. The evenly balanced arguments for and against such customs as 'bride-price,' initiation ceremonies or even polygyny, formerly denounced without question, demand a thorough understanding of the native point of view before insistence on a rigid adherence to conventional Christianity as practised in Western

Europe. The earlier days of missionary effort, with the drastic clearance of native beliefs and rites before instituting the new gospel, are passing away, and the newer tendency in religion, as in administration and legislation, is to preserve as much of native origin as can be incorporated or sublimated. This calls for the most careful research into the ideas and institutions to be selected, and more and more is the help of anthropology appreciated. Not only the outward form but the inner meaning has to be discovered, and modern missionaries must, in the words of one of their foremost leaders, become ' anthropologically-minded ' to avoid the errors of judgment of their predecessors. Christian missions, however valuable their contributions have been to education and civilisation, have often been responsible for bringing not peace, but a sword, and for disrupting rather than inculcating morality. For example, they have, in many cases, advocated, on religious grounds, the abolition of the youths' dormitory system, a valuable means of education in the community life of a village, and a useful check on adolescent extravagance. Polygamy has been attacked, and its prohibition has often had unexpected results. It led to such practices as abortion and infanticide in Melanesia, where cohabitation with a wife still suckling an infant was tabooed ; it has resulted in the expulsion and desertion of their older wives by converts in the Lhota Naga country, when they found that they could only reserve one ; while the abolition of the so-called ' bride-price ' among converted Sema Nagas produced a great instability of marriages which, it was felt, had no foundation of economic security.

Another result of missionary teaching has been the abolition of the feasts at which villages distributed their economic surplus and acquired merit and status. The feasts doubtless led to wasteful emulation ; but their abolition took away incentive to energy, led to apathy and lack of public spirit, to a general atmosphere of indifference and depression, resulting in some cases in a decline in population. Similarly the prohibition of arts, songs, and dances, and of folk culture in general, under the name of heathen customs, has frequently resulted in an apathetic attitude to life all too favourable for demoralisation and decay.

A student of the more primitive peoples cannot ignore the subject of religion which, in its widest interpretation, permeates their lives. For the anthropologist, religion ranges from the existence, real or postulated, of a vague feeling of awe in the presence of the unknown, through animism (the belief in spiritual beings), totemism (which defies brief paraphrase), sun and moon worship and ancestor-worship, to a belief in gods, a high-god—to polytheism, that is, and monotheism ; and if it does not include magic and fetishism, it finds it hard to draw a dividing line.

In the early days of investigation it was hoped, if not claimed, that by sifting the various religious beliefs of ' primitive man ' some basic fundamental principles would emerge. Some researchers have recognised some such foundation in animatism, in animism or in totemism, leading towards belief in a Supreme Being ; others have taken the opposite line and argued that a primitive belief in and worship of a Supreme Being had degenerated, had been later obscured if not obliterated by accretions, and ultimately diverted to ghosts and ancestors. Such universal evolutionary processes are no longer generally maintained. The study of comparative religion is more concerned with the discovery of the working of the human mind, and of the infinite variety of its religious manifestations. It has also a practical value. Religion has been called the master-key for the understanding of the ruder forms of society ; it is the mainstay of law and of government, and the very foundation on which society rests. This has been fully illustrated in the actual examples cited above of problems confronting the administrator and legislator no less than the missionary.

Folklore

The study of folklore is regarded as essentially a branch of social anthropology, but it is as difficult to dissociate it from religion. A new religion, superimposed on an old, turns its gods into devils and its beliefs into superstitions ; and these survivals from earlier cultures, lurking not only in primitive societies but latent often in the outwardly civilised, provide the material of folklore, illuminating secular as well as religious history. The study of tree-worship, taboos, the slaying of divine kings, of gods and of representatives of gods, the survivals found in planting and harvesting customs, in ceremonies connected with birth, betrothal, marriage and death—all these, familiar to the fascinated readers of *The Golden Bough*, show the fundamental unity of widespread beliefs and their indestructibility. Vegetation spirits, ancestor spirits, sun and moon gods, and so forth have indeed been found in unexpected places, often embedded in a more recent culture layer like extinct zoological forms preserved as fossils to a later age. These may explain puzzles in ritual and belief, while a comparison of folklore survivals among different peoples

may provide useful clues for the historian or even the ethnologist.

Thus in ancient Egypt the New Year began with the rising of the star Sirius, and was marked by the burning of the King as the earthly incarnation of the Sky God, reincarnated afresh in his successor. Later a human being other than the king was substituted. From that ceremony a carnival, likewise associated with the maintenance of the fertility of nature, has survived in all the later religions of Egypt and come down through the feasts of the Koptic Christian church to the Muslim population of the present day. On the Koptic New Year's Day they celebrate the procession of Abu Neruz—Father of the New Year—after which the mock king is condemned to death by burning, though in these more squeamish days his dress only is committed to the flames. So too, in Europe, the saints become the successors of pagan deities. The Virgin is worshipped as 'All-Holy Aphroditessa' on the site of the ancient temple of Aphrodite in Cyprus; the megaliths of an earlier faith are inscribed with Christian symbols or built into the walls of a parish churchyard; holy wells associated with pagan rites now bear the names of local saints—though in many cases the ancient rites are still (perhaps furtively) maintained. The perpetual fires of the Celtic goddess Brigit (whom the Romans identified with Minerva or with Vesta) survived in the nunnery of St Bridget at Kildare, perpetually guarded by the nuns, until Henry VIII suppressed both it and them at a date nearer to the present day than to that on which the fire was first kindled; and St. Bridget's Day is still observed on the eve of Candlemas. But folklore is not solely concerned with 'bygones.' It can discover the sources of much that appears irrational in the daily lives of men and women of the present day, and it can demonstrate the strength of the 'force of habit' and the hardness of the 'cake of custom,' which always and everywhere restrict mankind, civilised and uncivilised alike.

Language

Language was at one time believed to be a test of race, and by its means it was hoped to trace the history of man and his wanderings. That might have been possible had his history reached back less than the 6,000 years permitted by Archbishop Usher's chronology. But when it became evident that although linguistic clues might be discovered within this comparatively short period, man's history stretched back for a vastly greater space of time; that movements of peoples had been continuous; and that even within the historic period, languages could be borrowed and all traces of earlier speech lost; it was recognised that language, though a proof of culture contact, was no proof of racial affinity. There is the charm of simplicity about the idea of tracing Man's family tree back to the original Adam from whom we are all descended. There is a similar attraction in attempting to discover a parent language from which, by means of phonetic disturbances, the present multitudinous forms have sprung. For long the theory of the Aryan race and the Aryan language, both originating somewhere in Central Asia, held the field. The transference of the 'Aryan cradle' to Europe weakened the hypothesis, and before the end of last century the very word 'Aryan' in anything but a purely linguistic sense fell from grace and was excluded from scientific controversy. Its sinister reappearance in recent times, as noted above, is far from being a scientific resurrection. The study of language has nevertheless a definite place in anthropology. It is unnecessary to stress its importance to a worker in the field, for the value of his evidence is obviously reduced when obtained by means of an interpreter. Moreover a knowledge of their language is indispensable for gaining a people's confidence, as well as an insight into their thoughts and ideas. Language forms an integral part of any culture and needs to be studied together with all its other features. The character of a language reflects and reacts on the character of the people using it, for language can hardly exist apart from thought. The common belief that simple peoples have simple languages is found to be erroneous, as many examples show. The Fuegians, conspicuous for the meagreness of their material culture, yet possess an amazingly full vocabulary with a score of distinct and unrelated words where we are content with one or two. In fact the use of abstractions and generalised terms, which is characteristic of advanced languages, probably tends in some directions to a reduction of vocabulary.

Vocabulary is as valuable an indication of the interests of a people as a collection of their proverbs is of their philosophy. Some languages (like English) borrow easily from others; some assimilate intrusions with difficulty; some from patriotic motives attempt to expel even useful and well-established loan-words. These latter are an important help to the historian as well as to the anthropologist, as may be seen in our own case, where the introduction into English of Greek and Latin, Norman-French and French, Indian or Malay marks successive waves of invasion, eras of discovery, or the

impact of foreign cultures. The archæology of language, as exemplified in archaisms, can sometimes throw light on obscure customs or beliefs. Archaic words, often unintelligible to those using them, may accompany ritual, or form the substance of songs or spells, and, when analysed, may indicate their origin; archaic terms, often used in no other connection, may characterise relationships, as where 'mother-right' terms survive in a patrilineal society; and when an object appears in more than one culture under a name which can be shown to belong to an alien language, the argument that the object has been diffused rather than independently invented is convincing.

Method

Attempts have been made above to show what anthropology has done, is doing and can yet do, to provide a scientific basis for the solution of human problems, especially the problems of international and social relations. A few lines may here be inserted as to practical methods. In the matter of physical anthropology it has already been shown how, in attempting to determine racial affinities, recourse must be had to certain accepted criteria and the calculations derived therefrom. The character of the hair, shape of the head, colour of hair, eyes, and skin, measurements of the face, jaws, teeth, of stature and long bones, of bodily proportions and of weight, can be uniformly measured and statistical tables compiled. Estimates can be made of the size, weight, shape, proportions and convolutions of the brain. Recent work on blood tests adds to the evidence available. Some of the criteria for the living can be accurately collated with those obtainable from the dead; comparison can be made between past and present populations and past history reconstructed. Where sufficient material is available, interesting results may be deduced, as, for example, knowledge of the successive prehistoric invaders of Upper Egypt, or the notable changes in the physical type of Londoners from early times to the present day, while statistical data covering the present population can give valuable help in nutritional or labour problems.

Methods employed in cultural anthropology are necessarily far more varied, and it is impossible to compress a description into a short review. Mention may be made of Rivers' genealogical method of inquiry into kinship systems, and, to give an instance of another kind, the recording of string figures, which were used to facilitate lines of research towards the end of last century. But the technique of the field-worker must necessarily vary with the field no less than with the resources of the worker; the increasing size and range of advice given in successive editions of *Notes and Queries on Anthropology* indicate the advance in methods and their application, and even since the last edition was published in 1929 there have been marked advances in outlook and likewise in technique, while the training of women as anthropologists has led to a clearer appreciation of the position of women in uncivilised societies and to a better balanced review of social life. Social anthropology—the study of human societies—is becoming almost an independent branch of anthropology closely allied to sociology, though still generally confining itself to the smaller and less highly organised of human societies. Moreover, the social anthropologist no longer finds his main interest in societies living under primitive conditions and therefore in danger of becoming extinct at any rate in regard to the forms preserved from rapid change by isolation. Indeed societies of this kind have become so few that it would be increasingly difficult to restrict observation to them. Instead, social anthropologists of the younger generation are inclined to focus their attention on societies undergoing the process of change, and particularly on societies which are suffering from disturbance and *malaise* as a consequence of the impact of western civilisation, in order if possible to arrive at some diagnosis of the forces at work and a prognosis, if it may be, of the effects of measures of amelioration or at any rate of the nature of reactions to changed conditions. Anthropologists have therefore become investigators of cultural contact and of colonial administration. In this process the attitude and behaviour of Europeans in the Colonies has come in for study as well as the behaviour in society of the native inhabitants. This has brought the anthropologist into the fields of the economist and the lawyer as well as of the administrator. In Africa, in particular, important studies have been made of land tenures, marriage laws, and the effect of migratory labour on village life, and even into earnings and income with a view to the assessment of taxes.

Both in physical and cultural anthropology there have been recent developments calling for a much more advanced use of statistical methods. The physical anthropologist has always had to content himself with a limited series of observations, with the measurements of no more than a sample of the population he was studying. Nowadays his measurements and tests are being subjected to a much more strict mathematical discipline, while the cultural anthropologist likewise is being compelled to deal with the

growing numbers of persons coming within the range of his observations by methods of sampling, so to speak, that is by investigations limited to a portion only of a community in order to derive conclusions which shall be valid for the whole. Methods of this kind are familiar from such popular journalistic operations as 'mass observation,' or the 'Gallup Poll,' but it is perhaps hardly necessary to point out that if the result of proceedings of this sort are to be regarded as valid for the millions who constitute the populations so sampled, the actual number of observations required is very much in excess of those which usually seem to constitute the series investigated in the populations of modern civilised nations. The sampling method, however, has been used with success in census operations and in various sociological inquiries, and is now being applied to more anthropological inquiries into European as distinct from primitive communities.

Conclusion

An endeavour has been made above to set forth very briefly, and as simply as possible, the reasons for the study of anthropology and what that study envisages. An understanding of Man's past is a necessary preliminary to attempting any control of his future. Man has, perhaps merely by the possession of an opposable thumb and a succession of providential accidents, raised himself by the use of tools from a merely animal plane. (Some animals may be said to use implements of sorts but they do not *make* them, whereas man has gone so far as to make tools for making tools.) By the invention of language he is enabled to transmit the fruits of experience from generation to generation; and by the use of writing to multiply the store of transmissable experience indefinitely. The quantitative value of culture thus accumulated by society is not only infinitely greater than that which any generation can pass on by word of mouth, but the sum of knowledge transmissible grows in ratio to the size of the society transmitting it. None the less there are vast gaps in man's knowledge of himself. The study of anthropology not only broadens the mind by world-wide and ages-long views of humanity; it encourages a liberal outlook, and an appreciation of other ways of life and other points of view. The present distresses and confusions of the world are due in no little measure to ignorance, prejudice and misunderstanding, and to the deliberate perversions of truth which are thereby made possible. In the building up of a better world we shall need not only a knowledge of the past development of mankind, but a more intimate acquaintance and a greater degree of co-operation among men; above all, that understanding and tolerance which can spring only from knowledge—such knowledge as can be pursued and supplied by anthropology—the science of the study of Man.

FATIGUE

By Prof. E. P. Cathcart, C.B.E., F.R.S.

Fatigue is one of the most common states of discomfort felt by man. The word is descriptive of a condition of the body as a whole; it may be either physical or mental. It is for the most part a subjective state. Just as we are conscious of our willed movements so we are equally conscious of feelings of fatigue. We say we are tired, that we are done in, that we can do no more, we try in such words to convey the information that we are no longer capable of effective work. One of the most characteristic objective signs of fatigue is just this loss in effective capacity. We all know what is meant when an individual makes such statements after a period of muscular activity, either in doing manual work or taking strenuous exercise. But we cannot determine in ourselves or convey to another the degree of fatigue from which we suffer. No yardstick exists by means of which we can measure its intensity.

The late Prof. W. McDougall, in his report to the British Association nearly fifty years ago, drew attention to the many aspects of this interesting problem of fatigue, and gave the following simple example of its intriguing nature. 'I sit reading in the evening some difficult technical work until, as midnight approaches, I feel thoroughly tired and sleepy, my eyes smart and will hardly keep open, my head is dull and heavy and aches a little, my whole body and my limbs feel heavy and incapable of alert movement. I then take up some thrilling story or other fascinating piece of literature; whereupon all my subjective symptoms of fatigue, both tiredness and sleepiness, disappear and I read keenly for perhaps two hours, when I again begin to feel both tired and sleepy. Now suppose a continuation of the evening's history which is less familiar: some exciting event takes place just as I am

about to go to bed—the house takes fire or a burglar breaks in, or a friend comes in with important and interesting news that demands immediate action. Again, all the symptoms of fatigue disappear, and I can perform another spell of work at high pressure and without objective symptoms, and with little if any objective trace of fatigue —i.e. without appreciable diminution of efficiency.'

Fatigue may quite properly be regarded as a normal physiological condition which, in given circumstances, may become excessive and thus pathological, i.e. putting an undue strain on the organism. Fatigue is the natural sequel to hard or prolonged work. As already stated it is in the main a subjective phenomenon as, even after very hard muscular work, objective signs of fatigue, like muscle tremor and inco-ordination, soon disappear. Despite the disappearance of these objective signs the individual, although perhaps still keen, is normally quite incapable of performing further work, of voluntarily making any further effort. Yet —and this is an interesting feature of the problem—an individual, who has every appearance of complete exhaustion, may be capable of a spurt in production or, as the result of a strong emotional stimulus like fear, show an almost excessive reaction in the performance of some muscular feat which he could not have carried out under normal conditions, even although fresh and active. This is one side of the picture. The other is equally interesting, and probably on the whole more common, where a man who is ordered to work at a job which for some reason or other he dislikes, can become quite ineffective with an amount of work that might almost have been done by a child. This type of poor performance is not simply a case of 'ca' canny,' where an individual deliberately and maliciously reduces his output of work. In the first case the effect is quite involuntary, whereas in the second it is quite as definitely a voluntary act.

Cause of Muscular Fatigue

What then is the cause of muscular fatigue, of this diminution of function, skill and effort which is associated with the characteristic feelings of weariness and lessened capacity? Why is it there seems to be an increasing loss of power to make the muscles obey our will, to make them contract? Is there some incapacity of the nerves to convey the message which should evoke contraction of the appropriate muscles? Experiment has clearly shown that if a muscle is made to contract by artificial stimulation of the nerve, the extent of contraction will steadily diminish to zero. What has failed—the muscle or the conduction in the nerve? If the muscle, which has thus ceased to contract, be stimulated directly, by the application of a suitable electrode to the muscle itself, contraction will take place. Further, if the nerve to the muscle be tested, it can be shown that it is still capable of conduction. The failure then is due neither to the incapacity of the muscle nor of the nerve. So far as we know the failure in this case is due to some fault at the 'end-plate.' that is at the point of junction of the nerve with the muscle. But the exact nature of the change which is produced there—it is believed to be a chemical change—is still far from clear, although it is possibly due in part to an accumulation of toxic products of some kind or to the exhaustion of some essential intermediate substance. Diminution in the supply of oxygen to the muscle may possibly play some part in the process. These chemical changes, however, must be only a partial explanation of the phenomenon, for it leaves unexplained why and how an exhausted musculature can work with excessive power when excited by an acute emotional stimulus. It has been suggested that normally there is a factor of safety in the form of some kind of central inhibitor control, a control which may, in extremity, be released or broken down by an appropriate stimulus. Adequate explanations are certainly not lacking from want of experimental attack, but from the fact that the inner chemistry of muscle is not yet known to us.

Working Hours and Welfare

A mild degree of fatigue after a game of golf or tennis, for example, may be regarded as an almost pleasurable result of the exercise; but when fatigue results from too heavy or too prolonged work, as may occur in industry, it can become one of the factors which interfere with health. Exhausting degrees of fatigue in industry to-day occur as a rule in rush periods, when too long hours are worked. Few probably realise, except in a dim fashion, the enormous changes that have taken place in industry in the last hundred years. Let us look at some of the findings of the Children's Employment Commission whose report was published in the year 1843: 'That instances occur in which children begin to work as early as three and four years of age; not infrequently at five, and between five and six; while, in general, regular employment commences between seven and eight; the great majority of the children have begun to work before they are nine years old, although in some few occupations no children

are employed until they are ten and even twelve years old and upwards.' 'That in some few instances the regular hours of work do not exceed ten, exclusive of the time allowed for meals; sometimes they are eleven but more commonly twelve; and in great numbers of instances the employment is continued for fifteen, sixteen and even eighteen hours consecutively.' 'That in almost every instance the children work as long as the adults.' 'That in some processes of manufacture, as in winding for lace machines, the children have no regular and certain time whatever for sleep or recreation, being liable to be called upon at any period during sixteen, twenty or twenty-two hours out of the twenty-four, while they have frequently to go from one place of work to another, often at considerable distances, at all hours of the night, and in all seasons.'

Although over one hundred years ago men like Robert Owen and James Smith, who were looked upon by the majority of their fellow industrialists as unpractical, wrong-headed dreamers, had introduced many changes in their own factory practice for the increased welfare of their employees, their example was not generally followed. The abnormally long hours of work and the bad environmental conditions persisted practically unchanged in the majority of factories. In 1893 a far-sighted firm, Messrs. Mather and Platt, reduced, in their Salford Iron Works, their working week from 53 hours to 48 with results which satisfied both the employers and the employees, but their example was not followed by many. What may be called the scientific attack on the fatigue problem arose out of investigation made by the Health of Munition Workers Committee in the war of 1914–18. After the conclusion of hostilities there was set up by the Medical Research Council the Industrial Fatigue Research Board, a title which later was changed to the Industrial Health Research Board. This Board has carried out an immense amount of fundamental work both on fatigue and on the environmental conditions of the worker in the broadest sense of the term. Nowadays careful watch is kept by members of the Factory Inspectorate on the amount of work employees, and especially young adolescents and women, are called upon to do, and now many of the large up-to-date industries employ medical officers of their own to look after the welfare of their staff of workers.

Working Hours and Output

Despite all the evidence to the contrary, and it is abundant, the stupid belief still persists in many quarters that the longer the hours of work the greater the output: that if 10 units can be produced in one hour, 60 units can be produced in six hours, and 120 in twelve hours, and so on. This is a fundamental error. As the *Health of Munition Workers Report* puts it 'Misguided efforts to stimulate workers to feverish activity in the supposed interests of output are as useless as would be the cheers of partisans encouraging a long-distance runner to a futile sprint early in the race.' And this gross error has been exposed in actual practice. The fact is, that continuous activity on the part of human beings is sooner or later—it varies with the individual physique and make-up—inevitably associated with a decrease in the particular activity. With the onset of fatigue there is a definite fall both in the quantity and the quality of the output. It has been demonstrated beyond all question that long hours do not pay. When, for example, a group of men engaged on heavy work were investigated, it was found, as shown in the table, that a reduction in the hours of labour actually led to an increase in total output of 22 per cent.

Average hours worked per week.		*Relative hourly output.*	*Relative total (weekly) output.*
Nominal.	*Actual.*		
66·7	58·2	100	100
62·8	50·5	122	106
56·5	51·2	139	122

'Nominal' means hours spent in the factory.

'Actual' means nominal hours less time lost, for example, by waiting for material.

The same result was found in the case of women engaged from 66·0 to 47·5 actual hours per week on moderately heavy work, but in the case of youths engaged on light work the reduction of actual hours of work from 70·6 to 54·5 led to a definite fall in output.

Effort and Movement

An interesting point in the development of fatigue is that it is most readily developed in the carrying out of activities in which no measurable amount of work is done. The performance of muscular work has been divided into three forms, viz. positive work, when, for instance, a weight is lifted from (let us say) the floor to bench level; negative work, when the weight is lowered from bench level to the floor; and thirdly, static work, or more properly static effort, when the weight is maintained at constant level by the power of the muscles of the arm. The same static effort is manifest when a man is asked to move some heavy weight by means of a crow-bar. If the weight is too great, the man may

expend much energy and may even, if the strain is continued, collapse without moving the object a single inch. This is the type of 'work' which is most exhausting physically, the 'work' which most readily induces fatigue. It must be appreciated that the mere act of standing—that is of maintaining the body in an upright position—is, for the most part, a static effort and accordingly can readily produce fatigue.

There is a high factor of safety in skilled movement. When called upon to make a strenuous effort, the average individual begins, let us say, with his arms; then, if the effort is not sufficient to perform the special task, he braces his body to get more leverage by bringing his shoulder and leg muscles into play, and if these do not suffice the whole musculature of his body is brought into operation. Hence, to bring about an economical expenditure of energy for effecting the result required in the performance of any muscular act, the activities of the various muscles must be properly co-ordinated and integrated. In this way the organism is not unduly strained and there is the minimum of fatigue. Practice, either in sport or industry, simply means the ever increasing integration of the muscle groups required for the performance of the given act. We speak very often of an act, which is carried out smoothly and effectively, as having a perfect rhythm, that is the successive movements required for the performance have been properly integrated. Some investigators go so far as to say that this capacity for rhythmic action is one of the most fundamental properties of the nervous system. The perfection of this rhythm is the hall-mark of the skilled worker. But it must not necessarily be assumed that the rhythm which has been adopted by any one performer is the most economical from an energy expenditure point of view. Nevertheless, the movements employed, which have, so to speak, built up a reflex chain, can be carried out with the minimum of fatigue to the operator. Although such rhythmic activity may prolong the power to work, and thus the duration of the work period, they cannot, of course, abolish fatigue. There emerges still another interesting fact: that even if the most comfortable rhythm has been adopted, one which can be carried out without having to give thought to the act, once fatigue does begin to develop, the operation, if it has to go on, must be done more and more by voluntary effort. It is a well-known fact that once we begin to devote our attention to movements, the performance of which has become 'second nature' to us, they soon become slow, confused, difficult and fatiguing. Take, for instance, the case of a good golfer who for some reason or other begins to think about his drive or the position of his fingers or his stance. He is soon aware that his ease, flexibility and skill have departed—the ball he drove with faultless precision is now foozled.

Boredom

It is quite correct to state that when fatigue is induced there is a loss of effectivity and skill as well as the characteristic feelings of weariness and lessened capacity. There is more: we do not only become fatigued, which in the main is a bodily effect, but probably, in the majority of cases, we become bored and listless in mind, phenomena which have a central origin. In colloquial language we get 'fed up.' The feelings play a most important part in influencing both muscular and mental work. We all realise, at one time or another, the difference in our capacity to carry on physical or mental effort when irritated and bored and when we are contented and interested. The psychosomatic ('mind-and-body') aspect of the capacity to perform work is one of prime importance. In the case of boredom we are dealing with something appreciated centrally, something without any apparent physical basis, yet our capacity to carry on muscular work becomes increasingly difficult as boredom develops. Generally speaking, boredom arises when the work to be carried out ceases to be interesting or satisfying. If the work does not satisfy the creative spirit or the instinctive tendencies, does not, indeed, afford the operative a satisfactory stimulus, the work, depending largely on the psychological make-up of the individual, will increase the tendency to boredom. Yet even monotonous operations, if they do afford an adequate outlet, may become satisfying. One of the grave dangers associated with the genesis of boredom is that it arouses in the worker a state of restlessness which may pass into one of acute discontent. Moreover boredom, like fatigue, is manifested not only subjectively, it has its characteristic objective signs—irritability, bad temper, and other emotional disturbances.

Like fatigue, boredom is essentially a personal experience. There is no yardstick by means of which it is possible to measure its degree or intensity. The statements of the individual—notoriously unreliable—must be accepted. It would seem to be fairly clear, however, that the personal make-up of the individual plays a large part in his susceptibility to boredom. Generally speaking, it will be found that there is an inverse relationship between susceptibility to boredom and the level of the intelligence. The simpler

the psychic character of the worker, the less trying becomes the drabness of the work. The general expectation is to find boredom associated not with the performance of hard taxing muscular work, but with the lighter repetitive or so-called monotonous work. It is quite true that this is often the case but, on the other hand, we must be chary of claiming this as the outstanding cause. Very often the appraisement of monotony is that of the observer, not of the operative. Thus there are many who prefer to hold down an occupation which makes but little demand on their intelligence or attention and practically none on their responsibility. There is still another feature which must be considered in this connection: namely, that there is a degree of snobbery in all types of work, when the individual, due perhaps to a more extensive education or to some difference in social level, considers himself much too good for the job he is given to do. It is beneath his dignity. With the ever increasing use of automatic and semi-automatic machinery, the number of 'monotonous' jobs will certainly increase; while the number of workers who have received a much fuller education will steadily increase with the extension of the school age. Will boredom, and its subsequent discontent, increase? If so, can adequate outlets be devised to counteract this source of unhappiness and of ill health? Cannot something be done by arranging for the right use of leisure? Leisure time may be made creative.

Certain it is, and we all appreciate the fact, that if we receive an adequate stimulus when we are suffering from boredom, no matter how acute, the boredom forthwith disappears. In the case of many, who are apparently not bored and are performing simple operations well within their capacity, escape is achieved from boredom not by stimuli necessarily coming from without but, after having mastered their particular technique and having thus rendered the operation more or less automatic, by day-dreaming. Their hands perform the cycle of movements but their minds are elsewhere, luxuriating in past excitements and in excitements to come. They can replay the game their team lost last Saturday and devise new combinations in their team for the coming Saturday, or they can grapple with the never-ending problem of making their clothing coupons last out the prescribed period. It is true, however, that very often, many of these simple repetitive jobs are carried out with modern machinery at such a rapid rate as to demand the full attention of the operator, with the result that fatigue may almost replace boredom.

The problem of what is and what is not monotonous is full of interest because, quite apart from any very marked divergence in intellectual level, a job which will suit one man may be distasteful to another. Generally speaking creative work, the making of something in which the worker can take pleasure, is the ideal type of work, for even if it be confined to the making of a series of the same objects, it still, for most workers, continues to give satisfaction. The clay in the hand of the potter may, it is true, be employed in the making of replicas, but each in itself is new.

Measurements of Fatigue

Fatigue, as a practical problem, is largely an industrial one. Can the amount of fatigue generated in an industrial process be determined in a reasonably satisfactory practical manner, and if it is shown to exist can it be alleviated or abolished? Although it has proved impossible to measure the varying degrees of physical (and for that matter, mental) fatigue in an accurate and scientific fashion, various indirect methods of making a rough assessment of fatigue can be used. Thus:—

Variation in the output and quality of the work done.—This, on the whole, is the most reliable assessment as it measures performance in two distinct ways—quantity and quality of output. There is, of course, the objection that it gives but a small clue to the capacity of the individual employee. There are, moreover, certain practical limitations to its use as, before any reliance can be placed on the results: (1) the conditions of work must be kept constant, (2) there must be no variation in incentives offered, either monetary or other, and (3) there must be uniform methods and material. Not only must the amount of goods turned out be measured but also the amount of spoiled or defective goods. Generally speaking, it may be said that even where the working conditions are good the output, measured in hourly periods during the working day, does not remain constant, especially when the work is not automatic. There is, so to speak, a typical output curve—a gradual rise at the start of the day's work to a relatively stable plateau with a definite fall in the output towards the end. It has been suggested that an abnormal falling off towards the end of the day is a danger signal which must be watched.

Lost Time.—This has frequently been studied, and, as a gauge of the condition of the employee, it has its uses. The records which are kept in the workshop are very often not sufficiently accurate for statistical use; hence the real value of this index is difficult to define. As a generalisation it may

be said that the amount of time lost increases with the duration of the shift worked.

Degree of Effort Expended.—This method of assessment is of limited use as it is practically confined to processes, like grinding and polishing, where the amount of electric current used can be accurately measured by a recording watt-meter. It has been found that as the day progresses the time taken, per unit of work performed, and the amount of pressure exerted in each stroke on the polishing wheel and the duration of the stroke, showed a marked tendency to increase. The actual number of strokes made by each worker, however, did not show any very definite increase during the course of the day.

Labour Turnover.—This method of assessment, interpreted with caution, does give some clue to the work conditions existing in the factory. It may be that the environmental conditions are unpleasant, noisy, dirty, or draughty; it may arise from the nature of the material handled; it may be due to the fatiguing nature of the work carried out at high pressure.

Sickness Rate.—Again this is, as a rule, rather an index of internal conditions in the factory than of the capacity of the worker, but nevertheless it has been demonstrated quite clearly that as the hours of labour increase in the case of both men and women, the percentage time lost from sickness increases. Although the average results are quite clear it must be admitted that there are marked variations in this loss of time from month to month.

Accident Rate.—It is obvious that as fatigue increases, with its diminishing power of muscle co-ordination, there will be a tendency to an increase in the incidence of accidents. This increase is in its turn, in part at least, contingent on the environmental conditions in the factory, such as inadequate lighting and heating. At the same time it has been shown that in any group of workers there are a certain number who are accident-prone. These workers will always have a greater number of accidents than the other members of the main group of employees. This proneness would seem to be due to some inherent defect in their make-up. The majority of these accident-prone individuals can be eliminated by certain tests.

The only experimental method by which the genesis of fatigue can be studied accurately is that afforded by the use of ergographs and ergometers. The ergograph is an instrument which will record graphically the number of contractions made by a single group of muscles. This type of instrument was introduced by Mosso of Turin some fifty years ago. He was one of the first investigators in modern times to take up the study of fatigue. In his instrument a weight was lifted and lowered rhythmically by the contraction and relaxation of the muscles of the middle finger. The type of record obtained was uniform for all individuals tested—a full contraction at the outset followed, sooner or later, by a gradual diminution in the extent of contraction as fatigue set in. The only difference in the records made was in the duration of the period of activity.

In more recent times various types of ergometer have been used. These are instruments by means of which the amount of work done can be accurately measured. In principle the majority of these instruments are identical—most use a braked wheel. The results obtained can certainly give clear evidence of the genesis of fatigue but they give no clue to the nature of fatigue. However, they serve a most useful purpose in that the various methods of alleviating fatigue can be tested in a quantitative fashion. But they tend to oversimplify the problem. It is perfectly true that work on an ergometer can induce fatigue but it cannot give a full representation of the type of fatigue which occurs in industry. Generally speaking the fatigue induced experimentally is 'bodily' fatigue whereas in industry it is more often a 'body and mind' type of fatigue, a mixture of fatigue and boredom.

Prevention or Alleviation of Fatigue

As we know so little about the fundamental nature of fatigue, and as it is at present impossible to measure the actual degree of fatigue induced, have we at our disposal any method of preventing or of alleviating this condition? Obviously the amount of fatigue brought about in the performance of any piece of work can be reduced by shortening the length of the working day or altering the pace at which the work is done. Most people can walk a mile at their own pace without suffering from any undue fatigue. If an individual, however, is made to traverse this distance as fast as he can walk or at an abnormally slow pace he will inevitably suffer from fatigue to a greater or less extent, and yet the distance covered is the same each time. It is, then, not merely the distance covered and the time spent, but the rate at which the work is carried out which counts. As stated before, it is our natural rhythm, the rhythm which we normally adopt in the performance of work or play, which gives a certain amount of protection, although this rhythm may not be the most economical in energy expenditure. If we are going to

aim at economy of movement and manual dexterity, either in work or play—in, let us say, the coating of chocolates in a factory, or the playing of a game of golf,—the movements made by a really expert performer must be studied. To obtain the best results, moreover, the economic rhythm must be developed while the subject is young and plastic. The old adage that you cannot teach an old dog new tricks is in essence true. There was a very well-marked instance of this in the last war, and similar observations will no doubt have been made in the present war. At an old-established factory a new shop was erected and staffed so as to produce, calculating on the basis of the output of the older shop, 5,000 standard articles per week. An entirely new staff was recruited and specially trained. Within six months, in spite of the inexperience of the staff, 13,000 of the same standard articles were turned out each week. The old hands in the other shop, although the equipment was practically identical, could not approach this output. It may be remarked that there was no suggestion of ca' canny among the older workers.

Rest

But whether the correct economic rhythm is adopted or not, sooner or later the one real cure for fatigue must come into operation—rest. Effective rest may be of two types: one is absolute, and finally essential—sleep, with its complete physical relaxation. No matter what substitutes are put forward, sleep cannot be dispensed with. It is as essential for the relief of mental and physical fatigue as food, water, and fresh air are for the body; and it must be adequate in amount. The other type of rest, which certainly can alleviate fatigue, is change of occupation. When fatigue is first felt, before it becomes excessive, mere change of position, such as changing from a sitting to a standing position, will often prove effective.

Probably the best and most effective method for the prevention of undue fatigue for the majority has been the introduction of rest pauses in the spells of work. No worker ever works, except in special circumstances, 'all out' during a spell of work. From time to time he rests, sometimes of his own volition, sometimes involuntarily owing to lack of material. The duration of these unofficial rest pauses is more or less proportional to the severity of the work he is engaged upon. Now with the introduction of official rest pauses in many workshops there has not only been alleviation of fatigue but an increased output. It has further been found that the rest pauses are even more effective if the worker can have some refreshment like tea. The optimum duration of the rest pauses and whether they are equally valuable in both morning and afternoon shifts are still problems; it depends largely on the nature of the work done. As a general rule, because there is variation in response to rest pauses, a pause of ten minutes in the middle of the morning shift has proved most useful. The classic example of the effect of the introduction of a rest pause in the course of heavy work is that of Taylor, with a subject, Schmidt, carried out at the Bethlehem Steel Works: 75 men were normally employed on the particular job of loading pig iron, and the average amount loaded per man per day was 12½ tons. Taylor thought that this could be improved upon. He selected Schmidt for the experiment, and a man was set over him with a stop-watch. This man told Schmidt when to move and when to rest. Taylor had calculated that a good handler should be under load 43 per cent. of the working day and free from load 57 per cent. of the time to allow for recuperation. The end result was that Schmidt moved almost four times the load formerly carried—it rose from 12½ tons to 47½ tons per day. When an attempt was made later to get other men to work in this fashion, it was found that only one out of every eight men could conform. Schmidt, it may be noted, maintained this speed for three years.

Design of Tools

One of the most neglected methods of alleviating undue fatigue is lack of attention to the proper design of tools for the job they have to do. Take the simple example of the provision of a shovel to remove material. As a general rule one type of shovel alone is provided. But the material to be lifted varies widely in nature. Unit volume of one material may weigh many times unit volume of another, let us say for example, unit volumes of coke and iron ore. Yet the blade of the shovel provided is almost certainly the same in each case. For effective use it is the amount of material lifted at one operation which is the economic load. It has been determined experimentally that somewhere about 21 pounds lifted is such a load. The volumes of 21 pounds in the form of coke and iron ore are very different. When shovels were designed specially for each material, where the blade of the shovel carried the optimum 21 pounds, the average amount shovelled per man per day rose from 16 to 59 tons.

A study was carried out in this country by the Royal Engineers on trench digging. It was found that if a pick with a head weight of 6 pounds and a specially designed shovel were employed, in conjunction with modified

methods of using both implements, the average digging efficiency could be increased by 20 per cent. Carefully timed rest pauses were introduced into the work spell.

Workshop Design and Equipment

Closely related to the design of special tools is the design and lay-out of the workshop. The majority of workers in factories have to conform in their rate of working to the inexorable rhythm of the machines driven by overhead shafting. All must work at the same rate, and yet the natural working rhythm of the workers is not identical nor does it remain constant day in and day out in the same worker. Output both in quality and quantity, with a reduction in excessive fatigue, has been achieved where the ordinary overhead shafting has been replaced by individual motors, that is where the worker himself can control the rate of his machine. Moreover, the introduction of automatic and semi-automatic machinery and the increasing use of conveyors of one kind or another to obviate hand carriage is gradually eliminating the grosser forms of unskilled labour. To-day industry has but a limited use for the muscular Goliaths who were formerly a necessity ; the men in greatest demand now are the agile, intelligent Davids. Still a certain amount of carrying dead weights has to be done by the workers, and here it is found that it is the distribution of the load which is all-important in the alleviation of fatigue. The greater the disturbance of the centre of gravity of the body the larger is the number of accessory muscles called upon to maintain posture and the greater is the tax on the human body.

Psychological Alleviations

There are many other factors which have been shown to play an indirect part in the alleviation of fatigue. They may be loosely grouped as psychological. It is more comfortable and more stimulating to work in a clean, well lit, well ventilated, properly heated workshop where talking and singing are not forbidden, where the workers feel they are an integral part of the firm and not merely a collection of work units. As was stated in the Industrial Health Research Board Report, *Industrial Health in War*, 'sympathetic and understanding directors, controlling officers and foremen can by their very presence do an immense amount in the avoidance of undue fatigue' in their labour force.

One of the latest introductions into factory life is 'music while you work' in order to alleviate monotony and fatigue. There is no doubt that to the majority of workers it does afford relief. It has been demonstrated that it is most effective when played for about three-quarters of an hour on end towards the middle of the spell of work. But care must be exercised in the selection of the type of music played, partly because it may not fit in with the rhythm of the machinery and partly, perhaps, because it clashes with the individual rhythm. In simple form the effect of what may be called self-produced musical rhythm can often be seen, for example, in painters at work. If the man is whistling a quick and lively tune his brush moves in time with the beat, whereas if he whistles some slow and lugubrious air his brush moves at this tempo. In experiments which were carried out to test the effect of music in factory production it was noted that, generally speaking, foxtrots were preferred to waltzes, and marches with a strong rhythmic accent were disliked.

Mental Fatigue

So far emphasis has been laid on fatigue of the body, of the muscles for the most part. Reference must now be made to the analogous condition of mental fatigue. It is, of course, realised by all that mental fatigue is a common result of long-sustained mental activity. Further, we know, most of us from experience, that mental activity may give rise not merely to feelings of fatigue but also very frequently to a feeling of boredom. In ordinary everyday life it is realised that in most forms of activity, omitting those of a simple, monotonous type, there are processes of purposeful self-activity and others of a more mechanical type where the utilisation of acquired muscle integration comes into play. Prolonged activity should, and usually does, affect these two components in a different fashion. In the first there would likely arise some disorder of activity, whereas in the latter the most characteristic objective result would be diminution or even stoppage of activity, according to the degree of fatigue induced.

Mental fatigue and mental boredom are not apparently identical states, as the effective ease in alleviation is somewhat different. Fatigue is cured by cessation of mental activity, for preference by sleep, whereas the boredom may be effectively banished by simple resort to some congenial work as, in the main, boredom is due to the inability to find interests which will maintain spontaneous attention. Mental fatigue is a much more complex phenomenon. It has been suggested that our feelings of mental fatigue, and of course the unconscious processes relevant to these feelings, are the cause rather than the consequence of the impairment in

mental output following prolonged mental activity. Certain it is that the interpretation which we can apply to many of the phenomena of fatigue, both mental and physical, is far from satisfactory. How can the intense physical fatigue which very frequently follows an emotional disturbance, like extreme grief, be explained? It has also been suggested that the fatigue which is felt after strenuous mental activity does not reflect, at all stages, a really fatigued state of the mind, but that it represents a subtle factor of safety in that it may act as an inhibitor to protect such activity from developing into damaging fatigue. We do realise, however, that mental fatigue can, in many individuals when the strain is severe or prolonged, only too easily pass from what may be regarded as simple physiological fatigue, capable of abolition by adequate rest, to a severe pathological type due to overstrain which demands some form of psychotherapy.

Alleviating Drinks and Drugs

Both mental and physical fatigue can certainly be alleviated by the administration of certain chemical substances. Those most commonly used are alcohol and tea or coffee. It is perfectly true that these fluids can abolish the sense of fatigue, provided, of course, it is not too severe. It is generally believed that this action, in the case of alcohol, is due to its stimulant properties. As a matter of fact the belief that alcohol is a stimulant is quite unsound. Alcohol acts because it has the property of paralysing the central nervous system. Tea, or rather caffeine, the active constituent present in an infusion of tea, would seem to have a direct stimulant action and it has the additional virtue that there is no subsequent depression. The danger about alcohol is that it is quite definitely habit-forming. Its habitual use, therefore, for the alleviation of fatigue must be regarded as playing with a dangerous luxury.

Recently there has come to the notice of the public a group of drugs called analeptics (restoratives), of which benzedrine may be taken as an example. These drugs are effective in abolishing the sense of fatigue and when used with care, they have proved valuable. But, as with so many other valuable drugs, there are certain drawbacks to their general use. The effective dosage varies with different individuals ; a dose which may have no evident effect on one person will produce most of the signs of drunkenness in another. Further, as they interfere with the sense of judgment, a person who has taken one of these drugs will often have a very poor sense of his mental capacity, a state which obviously may be dangerous. If, on the other hand, the effective dose has been previously determined, the individual taking such a dose can carry on longer at high pressure than he would have been able to do under normal conditions. There is, however, a certain amount of evidence of a tendency to habit-formation. Whether taking these drugs over long periods has any bad effect is not yet known. Like other modes of alleviation, analeptics can be uncommonly effective, but again, as in the case of other methods, they can never do away with the need for sleep. Sleep remains the simplest and best method for the alleviation of all forms of fatigue.

MINERAL RESOURCES OF THE WORLD

(excluding Fuels and Water)

By David Williams, Ph.D.

Introduction

Minerals are of vital importance to modern industrial civilisation. They are the raw materials from which machines and power are manufactured, and without them there can be little material prosperity in times of peace nor effective capacity to wage war. The lure of minerals has inspired voyages of discovery and led to the development of uninhabited lands ; their possession has been coveted in the race for commercial supremacy and has engendered strife between nations.

Although man has prized gems and decorative stones since prehistoric times and has used certain metals, notably gold, silver, copper, tin, iron and lead, for more than 2,000 years, it was not until the industrial revolution in England inaugurated the machine age that mineral production received its first real impetus. Since then the increasing mechanisation of industries has resulted in an ever-growing demand for minerals and an accelerated exploitation of the world's mineral resources. During the past century the annual output of iron, the master metal, has multiplied a hundred-fold, that of copper more than sixty-fold, and the

production of many other metals has expanded even more rapidly. The introduction of manganese steel and other ferro-alloys towards the close of the nineteenth century revolutionised engineering and metallurgical practice, and heralded the age of special alloys. It was learned that by adding to steel small amounts of previously little-used elements, particularly chromium, nickel and tungsten, the metal became endowed with extraordinary qualities, including increased hardness, toughness, and resistance to corrosion. These alloying elements quickly assumed an importance out of all proportion to the amount consumed, and the geographical distribution of sources of supply acquired international significance.

Coupled with the vast expansion in mineral output there has also been, especially during the past twenty years, a growing demand for more varied supplies, until to-day more than a hundred different minerals are used in industry. Many elements formerly considered 'rare,' such as beryllium, cadmium, cerium, radium, selenium, tantalum and zirconium, are now in everyday use, and within recent years there has been a phenomenal increase in the consumption of aluminium and magnesium, particularly for light alloys required for aircraft construction.

The world's need of more food has involved a greater utilisation in agriculture of mineral fertilisers, which provide plants with essential phosphorus, potash, sulphur, and nitrogen. Since the last world war the annual production of these particular fertilisers has been doubled. In the rapidly expanding chemical industry no single commodity plays a more important role than sulphur, which is chiefly obtained from the two minerals, iron pyrites and native sulphur.

More minerals have been extracted from the earth during the past thirty years than in all preceding history. Fig. 1 illustrates the accelerated annual output of several essential metals between 1880 and 1940; during this period the production of pig iron and and manganese ore multiplied more than five-fold.

The Geological Control and Geographical Distribution of Mineral Deposits.

Man has no control over the location of mineral deposits, the distribution of which is governed by geological factors and has no direct relation to political boundaries. Workable deposits are scattered irregularly over the globe, and no nation is wholly self-sufficient in the great variety of minerals necessary for modern industrial requirements.

About 98·6 per cent. of the earth's crust is composed of eight elements, named in order of decreasing amounts: oxygen, silicon, aluminium, iron, calcium, sodium, potassium, and magnesium. Of these only aluminium, iron, and magnesium are of major industrial importance. Most of the other economic metals, such as copper, lead, zinc and tin, are present in amounts of less than one-fiftieth of 1 per cent. An ore deposit, from which one or more metals can be extracted with profit, can only exist if those metals have been segregated by some natural process of con-

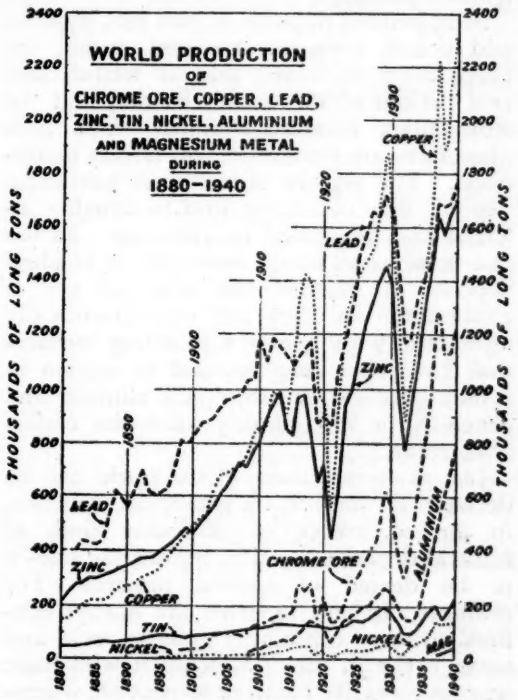


Fig. 1.

centration. This concentration is chiefly effected either at times of igneous activity, through the agency of hot aqueous and gaseous solutions emanating from molten lavas, or during periods of quiet sedimentation in seas and lakes. The weathering of rocks in place may give rise to mineral deposits by removing worthless material and thereby leaving a residue of valuable minerals, and surface streams may accumulate heavy minerals, such as gold, platinum and tin, by sorting action to form alluvial placers. After their original formation, mineral deposits are often exposed to prolonged oxidation at or near the surface, and may consequently be enriched to several times their former value.

Deposits related to rocks of molten (igneous) origin are usually connected with crustal folding movements and associated igneous intrusions, and are often spatially related to mountain systems that have been more or less deeply eroded by weathering agents, as in the

Andes, Urals, Caucasus, and Malaya. These deposits have generally been emplaced during one of the many geological periods of major crustal disturbance, the relative ages of which are broadly known. The precious metals (gold and silver), the ferro-alloy metals (chromium, cobalt, nickel and tungsten), the base metals (copper, lead, zinc, tin and mercury), and many minerals of importance in the chemical, refractory and electrical industries, such as pyrite, graphite, asbestos and mica, are normally won from deposits of igneous ancestry.

Most bedded deposits of rock salt, gypsum and potash were accumulated during the evaporation of inland seas at well-defined arid periods in the earth's history, and the sedimentary conditions under which rock phosphates are formed are now largely understood. The regions where these particular deposits may occur can thus be roughly inferred and delineated on the map. So too can those areas which may contain residual deposits of bauxite—the principal ore of aluminium, for they are characteristically associated with gently undulating surfaces that have been long exposed to erosion in a moist tropical or subtropical climate, and generally lie discordantly upon the underlying rocks.

Just as certain areas of the world can be declared favourable, on geological evidence, to the occurrence of particular kinds of mineral deposits, so other regions are known to be devoid of specific minerals. For example, tin and tungsten are always confined to areas containing granitic rocks and never occur in direct association with basic igneous rocks like basalt or serpentine, whereas the reverse is almost invariably true of primary chromite, nickel, and platinum deposits. In the vast regions composed of the most ancient (Archean) rocks it would be futile to search for coal, petroleum, phosphorite, or any other deposits of organic origin.

The main geological features of the earth's surface are now fairly well known, and many large areas in North America and Europe have been geologically surveyed in considerable detail. Nevertheless, there are still extensive promising regions that have so far received only the most cursory investigation, the outstanding examples being China, Brazil, and Soviet Asia ; many smaller areas, such as the Balkans, Indo-China, and portions of Central Africa, are also quite inadequately explored. Intensive prospecting for new deposits is now proceeding apace under the stimulus of war, and valuable discoveries have recently been made in the USSR, Brazil, and elsewhere. There is no reason to suppose, however, that there will ever be any radical alteration in our knowledge of the geographical distribution of mineral deposits, though the details of our understanding will increase with the passing of the years.

While formerly productive mining districts, like the Lake Superior belt, the Comstock Lode of Nevada, and the tin-bearing areas of Cornwall, have passed their zenith and are approaching exhaustion, other mining centres are still in their infancy or nearing maturity. But, although the main centres of production may shift from time to time, the movement is generally to places long known to be mineralised. Thus certain districts which were very small producers in 1918 have since leapt into positions of major status. During the past 25 years, for instance, Canada and the Belgian Congo have rapidly become the most productive sources of platinum metals and industrial diamonds respectively, and analogous spectacular increases have been recorded in the output of manganese in South Africa and the Gold Coast, of chromite in Turkey, South Africa and the Philippines, of copper in Chile and Northern Rhodesia, of tin in the Belgian Congo, and of iron, magnesite and phosphates in the Soviet Union. In most of these cases the recent quick development has resulted from the exploitation of resources which were at least partially known even before the outbreak of the last world war.

Statistics of Mineral Production

A rough guide to the localisation and magnitude of those mineral deposits that were being actively exploited during 1938 is afforded by the production statistics for that year, shown in Table I. It must be emphasised, however, that these statistics are not necessarily a reliable index to the mineral resources of a country nor a sure clue to its productive capacity. The volume of ore produced in a country merely indicates the extent of profitable mining being conducted within its borders, and may bear little relation to the potential reserves. Owing to a variety of economic and political reasons a country may possess large unworked mineral resources, the presence of which cannot be implied by statistical summaries of production.

The list of minerals in Table I does not include sand, gravel, limestone, clay, and building stones, which are produced in enormous quantities throughout the world, and are available in adequate amounts in nearly all countries. The compilation has been arranged alphabetically rather than by grouping the minerals and metals according to usage into ferro alloys, base metals, precious metals and stones, fertilisers, ceramics,

TABLE I.—WORLD MINERAL PRODUCTION IN 1938

Output of the Principal Nations expressed as Percentages of the World Totals

	Total World Production (In Thousands of Long Tons)	British Empire	U.S.A.	USSR	France	Germany	Italy	Japan	British Empire (in brackets), and other Important Sources
Antimony	*32*	0	2	D	0	0	2	0	Bolivia 27, China 24, Mexico 23, Yugoslavia 10.
Arsenic (1936)	*75*	5	14	=	20	4	0	3	Sweden 40, Mexico 9.
Asbestos	*450*	75	3	19	0	0	1	0	(Canada 57, S. Rhodesia 12, Union S. Africa 5).
Barium	*1,000*	9	30	10	2	47	5	0	(United Kingdom 8)
Bauxite (Aluminium Ore)	*3,788*	12	8	7	18	1	9	0	(Br. Guiana 10), Dutch Guiana 10, Hungary 14, Yugoslavia 10, Netherlands E. Indies 7.
Bismuth	—	—	—	—	—	—	—	—	Peru, Mexico.
Borates	*217*	0	90	d	0	0	3	0	
Bromine	*17*	3	85	0	3	8	1	0	(Palestine 3).
Cadmium	*5*	16	40	2	2	9	1	0	(Canada 7, Australia 4, United Kingdom 3), Mexico 16.
China Clay (1937)	*3,095*	28	21	=	4	12	4	13	(United Kingdom 27), Czechoslovakia 21.
Chromite	*1,100*	37	0	18	0	0	0	4	(S. Rhodesia 17, Union S. Africa 16, India 4), Turkey 19.
Cobalt	*4*	48	0	0	0	0	0	0	(N. Rhodesia 38), Belgian Congo 34, French Morocco 18.
Copper	*2,020*	30	25	5	0	2	0	4	(Canada 15, N. Rhodesia 15), Chile 17, Belgian Congo 6.
Diamonds (Thousands of metric carats)	*11,455*	30	0	0	0	0	0	0	(Gold Coast 11, Union S. Africa 11, Sierra Leone 6), Belgian Congo 63, Angola 6.
Fluorite (1937)	*508*	12	32	13	10	28	3	0	(United Kingdom 8), Chosen 2.
Gold (Thousands Fine ozs.)	*37,300*	57	11	14	0	0	0	2	(Union S. Africa 33, Canada 13, Australia 4).
Graphite (1936)	*210*	7	2	37	0	11	2	1	(Ceylon 6), Chosen 19, Austria 10, Mexico 5, Madagascar 4.
Gypsum	*9,000*	24	27	=	14	19	5	2	(United Kingdom 12, Canada 10).
Iron (1937)	*96,500*	10	38	14	14	3	1	2	(United Kingdom 4, India 2, Australia 2), Sweden 9.
Lead	*1,780*	35	19	=	0	5	2	1	(Australia 15, Canada 11, Burma, 5, United Kingdom 2), Mexico 16, Yugoslavia 5.
Magnesite (1937)	*2,150*	2	8	37	0	1	0	0	Austria 21, Manchukuo 15, Greece 7.
Manganese Ore	*5,800*	32	0	50	0	0	1	1	(India 17, Union S. Africa 9, Gold Coast 6), Brazil 4.
Mercury	*5*	0	12	6	0	0	44	0	Spain 28, Mexico 6.
Mica (sheet)	*7*	78	6	=	0	0	0	0	(India 77), Madagascar 9, Brazil 7.
Mica (scrap)	*23*	20	80	=	0	0	0	0	(India 14, Union S. Africa 5).
Molybdenum	*16*	0	92	0	0	0	0	0	Mexico 3, Norway 3.
Nickel	*113*	84	0	2	0	0	0	0	(Canada 84), French New Caledonia 11.
Phosphates	*12,400*	11	26	14	0	0	0	2	(Nauru and Ocean Islands 9), Tunisia 15, French Morocco 12, Algeria 5.
Platinum metals (Thousands of Troy ozs.)	*552*	64	9	22	0	0	0	0	(Canada 53, Union S. Africa 11), Colombia 5.
Potash (K_2O)	*3,100*	1	9	8	18	59	0	0	(Palestine 1).
Pyrites	*10,000*	11	6	10	1	4	9	20	(Cyprus 8), Spain 27, Norway 10, Portugal 5.
Salt	*32,000*	16	22	13	5	10	5	2	(United Kingdom 8, India 5), China 9.
Silver (Millions Troy ozs.)	*267*	18	23	3	0	3	0	4	(Canada 8, Australia 6), Mexico 30, Peru 8
Strontium	*5*	94	0	0	0	6	0	0	(United Kingdom 94).
Sulphur	*3,200*	5	75	=	0	2	12	5	
Tin	*160*	40	0	0	0	0	0	1	(Federated Malay States 26, Nigeria 5), Netherlands E. Indies 17, Bolivia 16, Siam 9, China 7, Belgian Congo 6.
Titanium (Ilmenite)	*337*	77	1	0	0	0	0	0	(India 75), Norway 19, Senegal 3.
Tungsten (60 % WO_3)	*36*	24	8	0	0	0	0	0	(Burma 18, Australia 3), China 37, Portugal 8, Bolivia 7, Chosen 6.
Vanadium	*3*	35	27	0	0	0	0	0	(S.W. Africa 21, N. Rhodesia 14), Peru 31, Mexico 7.
Zinc	*1,840*	30	25	4	0	11	4	1	(Australia 12, Canada 10, Newfoundland 4, Burma 3), Mexico 9, Poland 4.

Tonnages of metals refer to the estimated metallic content of the ores.
D Large deficiency. d Deficiency. = Sufficiency.

refractories, etc., because so many individual minerals are now used for widely different purposes.

The following statistics, adapted from a recent American publication,[1] indicate the monetary value of the world's mineral production during 1939, measured in £ sterling[2]: percentages of the total values provided by the various countries are also given :—

Total value of Metals (*excluding Gold*) = £439 million.

U.S.A. 24 % ; Canada and Newfoundland 10 ; USSR 9 ; Chile, Mexico, Australia, Germany and Austria, France 4 each ; N. Rhodesia, Malaya, Sweden, India 3 each ; Japanese Empire, Belgian Congo, Yugoslavia, British Isles 2 each ; others 17.

Total value of Gold = £308 million.

Union South Africa 33 % ; Canada 13 ; USSR 12 ; U.S.A. 12 ; Japanese Empire 5 ; Australia 4 ; others 21.

Total value of Non-Metals (*excluding Fuels*) = £98 million.

U.S.A. 21 % ; Germany and Austria 20 ; USSR, France 7 each ; Union South Africa, Canada and Newfoundland 5 each ; Italy 4 ; United Kingdom, China, Belgian Congo 2 each ; others 25.

Total value of Minerals (*excluding Fuels*) = £845 million.

British Empire 37 % ; U.S.A. 19 ; USSR 10 ; Germany 4 ; Japanese Empire 3 ; others 27.

Total value of Fuels (*Coal, Petroleum, etc.*) = £1,175 million.

U.S.A. 45 % ; USSR 10 ; Germany 10 ; United Kingdom 9 ; Venezuela 4 ; Japanese Empire, France 2 each ; others 18.

Measured in terms of value three of the Allied Nations—the British Empire, U.S.A., and USSR produced 66 per cent. of the world's minerals (excluding fuels), whereas the Axis Powers—Germany, Italy, and Japan produced only 9 per cent. of the total. The respective proportions of the total world output of minerals, including fuels, were 67 and under 11 per cent.

Interdependence of Nations on Mineral Supplies

Industrial technique has become so complex and the demand for minerals so diverse that no country, indeed no continent, has adequate supplies of the essential mineral raw materials. National self-sufficiency in minerals cannot be attained even under the urgent stress of war, and as 'new,' comparatively rare minerals enter the expanding field of industry, nations become ever more interdependent for their mineral supplies. Freedom of access to these supplies and their uninterrupted international flow are thus prerequisites to the economic prosperity of industrial nations, and the imposition of restrictions on world trade in minerals endangers peace.

The dominating position in world affairs of the industrialised Powers, Great Britain, U.S.A., France, Germany, and latterly the USSR, is largely due to the chance that each of these countries contains immense deposits of coal and iron closely grouped within its own borders. The presence of these two materials has determined the location of industrialised areas, and up to the present the prevalent movement of other minerals has been towards these manufacturing centres.

Seventy years ago *Great Britain* was practically self-contained in mineral supplies, for she had the ingredients for making ordinary iron and carbon steel, and was a foremost producer of copper, lead and tin, the needs for which were then relatively slight. With the advent, during the last quarter of the nineteenth century, of manganese steel and other ferro-alloys with special physical properties, Britain's economic independence ended, for the vital constituents of the new steels had to be imported from overseas. At the same time, easily worked base-metal deposits were opened up in many parts of the world, causing Britain's small copper, lead and tin mines to languish into comparative insignificance. Apart from coal, the mainstay of her industry, iron ore (mostly low-grade), barium, china clay, fluorite, gypsum, salt and strontium, the United Kingdom is now almost entirely dependent on Empire and foreign sources for her mineral supplies, the severance of which would quickly cripple her life as an industrial nation.

Even though the *British Empire* has a surplus of total mineral resources, with virtual world control of nickel, gold, platinum, asbestos and strontium, and an excess of lead, zinc, tin (before Malaya fell), chromite, manganese, cobalt, diamonds, radium, and sheet mica, nevertheless she must rely almost wholly upon outside sources for antimony, borates, mercury, molybdenum, potash and sulphur, and has to import considerable quantities of other minerals, including bauxite, magnesite, and phosphates.

The position of the *United States of America* as an outstanding manufacturing country is due to her vast mineral wealth, which includes abundant reserves of fuels, iron, copper, lead, zinc, phosphates, sulphur, etc. (see Table I).

[1] *World Minerals and World Peace.* C. K. Leith, J. W. Furness and C. Lewis. Brookings Institution, Washington, D.C. 1943.

[2] In 1939 the £ sterling averaged 4.43 dollars.

Yet in pre-war years she had to import about 95 per cent. of the manganese essential for her enormous steel industry, and besides lacking diamonds, nickel, and tin, she is deficient in chromium, tungsten, platinum, antimony, asbestos, sheet mica and several other mineral commodities. These deficiencies are partly due to her immense consumption, and have been ameliorated somewhat during the present war by the exploitation of low-grade deposits, though there is little prospect of any improvement in the domestic supply of diamonds, nickel, and tin.

The development of mineral resources in the *Soviet Union* during the past sixteen years has far surpassed anything formerly achieved in a like period of the world's history. It may well be that as a result of intensive scientific prospecting the USSR will eventually become almost entirely self-supporting, and be able to export large amounts of coal, iron, petroleum, manganese, platinum, magnesite, phosphates, asbestos, potash, and sulphur. But despite her riches it seems unlikely that she will ever possess adequate supplies of tin, tungsten, and possibly nickel.

If these three great political units, the British Empire, the United States, and the Soviet Union, are each dependent on outside sources for some essential minerals, then it is obvious that other nations must rely even more upon mineral imports for their industrial requirements.

National Self-Sufficiency

The degree of domestic self-sufficiency of a country is measured by the proportion of mineral consumption that can be supplied by home production under normal conditions of international competition and trade. Consumption statistics of a particular mineral are difficult to estimate, but are often roughly based on figures for total production plus imports, less exports.

Clearly, the status of industrial development of a country is a cardinal factor in determining its degree of domestic self-sufficiency. Thus, the United States, owing to her immense manufacturing capacity, may be deficient in certain minerals and yet produce more of them than less industrialised nations which export those specific minerals.

In Table II the self-sufficiency ratings for the principal economic minerals are listed for the leading countries, according to production statistics for 1938. Of the 23 minerals indicated the British Empire is more or less deficient in 7, the USSR in 10, the United States in 14, the French Empire in 15, Italy in 16, the Japanese Empire in 18, Germany in 19, and Great Britain in 22.

It must be emphasised that Table II does not necessarily reflect the comparative status of mineral resources in the various countries named, because the standard of domestic self-sufficiency is largely influenced by the industrial rank of the individual country and by financial considerations. Various authorities have attemped to assess the relative production capacity of different countries by assigning arbitrary weights to the separate minerals according to their industrial importance. In such assessments, since iron and copper are obviously more significant than, say, fluorite and graphite, the former pair of metals are rated more highly. The

Table II.—National Self-sufficency in Principal Minerals

	Metallics								Non-metallics							
	Great Britain	British Empire	U.S.A.	USSR	French Empire	Germany	Italy	Japanese Empire		Great Britain	British Empire	U.S.A.	USSR	French Empire	Germany	Italy	Japanese Empire
Antimony	0	0	−	0	0	0	0	0	Asbestos	0	+	0	+	0	0	−	0
Bauxite	0	=	−	−	+	−	+	0	Borates	0	0	+	−	0	0	+	0
Chromite	0	+	−	=	=	0	0	=	Diamonds	0	+	0	0	0	0	0	0
Copper	0	+	+	−	0	−	0	−	Fluorite	+	+	=	=	=	+	=	=
Iron	−	=	+	+	+	−	−	−	Graphite	0	+	−	=	+	=	=	+
Lead	0	+	=	−	0	−	−	0	Magnesite	0	−	=	+	0	+	−	+
Manganese	0	+	0	+	0	0	−	−	Mica, sheet	0	+	0	=	0	0	0	0
Mercury	0	0	−	−	0	0	+	0	Phosphates	0	−	+	+	+	0	0	−
Nickel	0	+	0	−	=	0	0	−	Potash	0	0	−	=	+	+	0	0
Platinum	0	+	0	+	0	0	0	0	Sulphur	0	0	+	=	−	−	+	+
Tin	−	+	0	0	0	0	0	−									
Tungsten	0	=	−	0	0	0	0	−									
Zinc	0	+	=	=	0	−	=	−									

\+ Surplus supply; minerals available for export.
− Important deficiency.
= Supply adequate, or nearly so.
0 Negligible or entirely absent.

more equitable weighted results so obtained serve to stress the dominant position of the British Empire, the United States, and the USSR as compared with other nations.

Access to Mineral Supplies

It is one of the tenets of the Atlantic Charter that all countries should have access, on equal terms, to the trade and to the raw materials of the world which are needed for their economic prosperity. Few would deny the right of every country to unrestricted access to mineral supplies for purposes of peace, but not in order to amass armaments. Among the so-called ' have-not ' nations—Germany, Italy, and Japan, there has long been a persistent cry for freedom of access to the world's mineral wealth, and each of these poorly endowed countries has resorted to aggression in an endeavour to alleviate some of its mineral deficiencies.

Investigation of pre-war conditions reveals that no country has been barred from obtaining large quantities of strategic mineral raw materials, even though they were coveted mainly for the manufacture of armaments. It is significant that imports of strategic minerals, such as iron, manganese, nickel, tungsten, and copper ores, into the Axis countries reached a high peak in 1937 and 1938. Indeed, commercial interests among the chief Allied Nations were only too anxious to sell the sinews of war to the predatory powers. In the years immediately before the outbreak of war Germany imported immense tonnages of iron ore from France and Algeria; manganese from South Africa, USSR, and India ; copper from the British Empire, Belgian Congo, and the United States ; nickel from Canada ; chromite from South Africa and Southern Rhodesia ; and tungsten from China. Japan bought millions of tons of iron and steel, together with vast amounts of molybdenum, copper, and other essential metals from the United States, in addition to lead and zinc from Canada, and tin from Malaya. Italy's preparation for war was no less facilitated by her ability to procure the necessary minerals from those countries she was about to assail.

The fact that highly developed iron and steel industries flourished in Great Britain, United States, Germany, Japan, France, and Belgium-Luxembourg in the period between the two world wars, obviously implies that those countries must have had access to foreign supplies of such essential ferro-alloy metals as manganese, nickel, chromium, tungsten, and cobalt, in which they were themselves deficient.

Trade barriers, such as the imposition of export and import tariffs, embargoes, quotas, the operation of cartels and monopolies, and the urge towards nationalisation of minerals have undoubtedly interfered to a limited extent with the international flow of mineral commodities, but there is no evidence of deliberate discrimination against the ' have-not ' nations. It seems true to assert that, in general, there have been few serious restrictions to the traffic in minerals, other than those arising from exchange depreciation in the importing countries. So long as nations are imbued with the will to peace there should be no restraints to the world-wide trade in minerals.

Ore

' Ore ' is a term often loosely used to define any material that is mined, though technically the word refers to rocks from which one or more metals can be profitably extracted. Those geological bodies containing accumulations of metallic or non-metallic minerals that can be mined and marketed at a profit are classed as mineral deposits. An ore deposit may yield several metals from different ore minerals, and the accompanying non-metallic materials, such as quartz and fluorite, often provide valuable by-products. The payability of an ore body depends upon many variable factors, including the amount and selling price of the metals, the cost of mining, treating, transporting, and marketing the products. A rise in price may make it possible to extract leaner parts of the deposits, whereas a drop might preclude their profitable exploitation. Thus the size of an ore-body is not fixed, but varies with fluctuations in the price of metals.

Improvements in mining methods and in metallurgical technique often bring within the range of commercial ore materials that were previously discarded or unworkable. For example, low-grade copper deposits in the United States and Chile, which were regarded as worthless in 1900, have contributed about half the world's copper output within recent years. This has been accomplished by efficient large-scale mining and by the employment of differential oil-flotation methods of ore dressing. Ninety years ago most of the copper ore sent for treatment averaged more than 20 per cent. copper ; to-day immense tonnages of ore containing less than 1 per cent. of the metal are being treated successfully in America and elsewhere. Many iron ores rich in phosphorus, such as those of Belgium and Germany, were neglected until about 1878, when the Thomas ' basic process ' of steel-making provided the means for their economic exploitation. And the most productive zinc district in the world, centred around Joplin, Missouri, is actually

dependent upon low-grade ores, formerly considered to be practically valueless. Just as the useless of yesterday has frequently become the useful of to-day, so in the future improved processes of reduction and the utilisation of minerals new to industry will certainly result in the mining of deposits now undisturbed.

Accessibility is another important factor by which the value of an ore is measured. Many a rich deposit far distant from lines of transportation and smelters is of less value than a leaner body which is more conveniently located. The low-grade copper deposits of Western United States can compete with the much richer ores of the Belgian Congo and Northern Rhodesia because the former are nearer to centres of consumption, and therefore entail considerably less cost of transportation to the markets. Although the high-grade iron ore deposits of Minas Gerães, Brazil, are probably the largest in the world and were discovered many years ago, their comparatively inaccessible position and the lack of transport facilities have delayed their large-scale exploitation until quite recently. Size and ease of mining also weigh heavily in assessing the value and workability of an ore-body. Only after drilling had proved the existence of hundreds of millions of tons of readily accessible ore was it justifiable to open up many of the great copper deposits of America and Central Africa. On the other hand, many rich ore-bodies remain unworked because they are too small to warrant the installation of costly equipment.

The ore minerals in a deposit are commonly mixed with worthless minerals or rock matter, called gangue. Frequently, however, the gangue materials can be utilised as by-products, and as a result of technological discovery these may prove to be of great value. In many instances the profitable operation of an ore-body depends upon the presence or absence of certain gangue or accessory minerals. Thus the economic working of a poor lead ore may hinge upon its silver content, and the decision to mine a pyrite or copper deposit is sometimes favourably influenced by the presence of traces of gold in the ores. Conversely, a high arsenic content often militates against the successful development of an otherwise payable deposit of iron or copper ore, and a high silica percentage seriously detracts from the value of bauxite, the chief ore of aluminium.

Tenor of Ores.—The metallic content or tenor of an ore is of outstanding importance, and the minimum values which ores of the different metals should contain for profitable exploitation are fixed by economic considerations. Since gold is more than 40,000 times as valuable as an equivalent weight of iron, and is worth 10,000 times its weight of lead, then obviously the tenor of payable gold ores can be very much lower than that of the poorest ores of the other two metals. Indeed, in some gold mines the precious metal is so scarce and finely disseminated that diligent search is necessary to discern even a speck of visible gold. At the Juneau gold mine in Alaska, ores with less than 0·0001 per cent. of gold are being mined with profit, whereas iron ores containing less than 30 per cent. of the metal can seldom be worked economically in normal times, and few lead mines are able to treat ore with less than 5 per cent. metal.

When necessity outweighs economy, as in times of war, or when mining is conducted under a socialist regime like that of the Soviet Union, production may be obtained from deposits which would be unprofitable to work under normal circumstances of free competition. Thus in the United States intensive and successful attempts have recently been made to augment the domestic output of low-grade chromite and manganese ores for the manufacture of armaments despite the high cost of production relative to the normal price of imported ores, and even before the war the Soviets exploited many ore-bodies which could not have been mined economically under private enterprise.

The Discovery of Mineral Deposits

The great majority of known deposits have been found because they were visible at the surface, and many were discovered accidentally. Nickel was first identified in the Sudbury district of Ontario in 1856, but it was 27 years later that a blacksmith working with a construction gang on the Canadian Pacific Railway noted copper pyrites glistening in a fresh cutting, and so attracted attention to an area which now produces about 90 per cent. of the world's nickel. Like Sudbury, the fabulously rich silver ore of Cobalt, in Northern Ontario, was found incidentally during the building of a new railroad. The discovery of a brilliant stone among the pebbles collected by children playing on the banks of the Orange River, and a shepherd-boy's find of a perfect white diamond (later named the 'Star of Africa') led to the development of the great diamond industry of South Africa. Broken Hill, New South Wales, famous for its lead-zinc-silver ores, was discovered more than half a century ago by a boundary-rider who mistakenly imagined he had chanced upon a deposit of tin ore.

It would be difficult to over-estimate the debt which the mining industry owes to the hardihood, perseverance, and skill of the old-

time prospectors and diggers. Travelling on foot, with a donkey, or by canoe, armed with hammer and washing pan, and imbued with optimism, they roamed the wilds in search of El Dorado. Many of these rugged men, although illiterate, had an uncanny 'nose for ore,' and to them stands the credit for discovering rich mineral wealth. They panned alluvial gravels to trace valuable minerals upstream to their source in the mother lode, followed up ore fragments in glacial deposits to their starting-points, and trenched through the iron-stained caps that overlay sulphide deposits. Scores of mining districts, including the great Witwatersrand goldfield of the Transvaal, perpetuate the memory of these indomitable souls.

Outcropping ore-bodies will still be found in the unexplored regions of the globe, but the chances of such easy discoveries grow smaller, and it becomes increasingly difficult to locate new deposits without recourse to scientific prospecting under geological guidance. It is common practice nowadays for geologists and 'practical prospectors' to co-operate in exploratory teams, and for large mining organisations to employ a group of expert geologists for systematic areal prospecting and for directing underground development. After broad reconnaissance, work is concentrated on those areas where the geological conditions appear to be favourable for mineralisation, and detailed attention is devoted to the structural features of the rocks, igneous intrusions and contacts, rock alteration, and other considerations bearing on the control of mineralisation. Very often the mineral deposits are concealed beneath a thick mantle of overlying rocks, and careful geological deduction is necessary in order to predict their position with any assurance. Probably the most outstanding recent achievement due to scientific prospecting by geologists has been the development of the world's greatest copper deposits, those of Northern Rhodesia, which are now known to contain the equivalent of more than 20 million tons of metallic copper. Elsewhere, and especially in the Soviet Union, numerous important mineral discoveries have latterly been made by trained geologists. That the realistic authorities of the USSR should consider it well worth while to employ thousands of geologists in prospecting throughout the Union testifies to the value of scientific exploration, and the amazing development of mineral resources in that country during the past two decades has been due in no small measure to the efforts of the Soviet geologists.

In considering the possibilities of future discoveries it must be emphasised that over most of the earth's surface the proportion of exposed rock is extremely small, and that over wide tracts no outcrops are visible, the solid rocks being blanketed by glacial drift, other overburden, and vegetation. Moreover, mineral deposits formed in earlier geological periods are generally deeply covered by later sediments and volcanic rocks, and there can be little doubt that more deposits are so concealed than are exposed at the surface. The present topography is, in a sense, a chance surface of erosion; deeper erosion would unquestionably bring to light unsuspected mineral wealth, though it would also sweep away many deposits now being mined. Even the most meticulous geological mapping may sometimes fail to provide any indication of nearby ore, even though it actually lies at shallow depths. A few more great mineral districts, such as the Witwatersrand goldfield, the nickel deposits of Ontario, the Lake Superior and Brazilian iron ore deposits, or the copper belt of Northern Rhodesia may yet be found by locating their outcrops, but the discoveries of the future will come increasingly from deep exploration in areas of known mineralisation and from regions where the mineral deposits are masked by overlying rocks.

Fortunately, a relatively new method of exploration, that of *geophysical prospecting*, has come to the aid of the geologist in deciphering concealed geological structures and in searching for hidden deposits. The application of this branch of prospecting has already met with spectacular successes, especially in oil exploration, and will certainly become more widely adopted in future mining exploration. The fundamental requirement in geophysical prospecting is that there should be a pronounced difference between some physical characteristic of the deposit or structure to be located, and that of the surrounding rocks. As a rule, the methods employed merely measure differences in physical properties of the rocks, and do not reveal directly the presence or the precise nature of a mineral deposit. For the most effective interpretation of the results of geophysical surveys the co-operation of geologists and geophysicists is virtually essential.

In the domain of metal mining, geophysics assists in the location of new ore-bodies and the extensions of known ones, in determining the extent of mineralised areas, in finding faulted segments of veins, and in delineating rich ore shoots. In non-metallic mining it helps in ascertaining the thickness of overburden, the presence of faults and other geological structures, and the areal extent of buried rock formations, such as beds of coal and lignite, and diamond-bearing pipes.

As applied to the search for minerals other than oil, the chief methods used are magnetic,

electrical, and electromagnetic. It has long been realised that magnetic bodies within the earth cause a distortion of the normal magnetic field, which can frequently be detected by observing the deviation of a compass or dip needle. Most magnetic anomalies are due to iron-bearing igneous and sedimentary rocks or to ores containing compounds of the metal. Delicate instruments are now employed which can distinguish minute differences in the magnetic susceptibilities of rocks, and are capable of detecting deposits of magnetic iron at depths of over a mile. They have been used with success in locating bodies of magnetic iron ore, nickel sulphide, and basaltic lava-flows carrying copper.

A great variety of electrical methods can be applied to the discovery of metallic mineral deposits, which usually have a low specific resistance and a higher electrical conductivity than the surrounding rocks. In the spontaneous polarisation, or self-potential method, no outside energising force is required, since the oxidising ore-body itself acts as a battery and is a natural source of current that can be detected at the surface by a sensitive galvanometer. Generally, however, currents are introduced artificially into the ground, and, by measuring potential differences at the surface, it is possible to determine the extent of buried deposits having anomalous conductivity, such as a highly conductive copper ore. The Buchans lead-zinc mine, in Newfoundland, was discovered in this way.

Electromagnetic methods make use of the well-known principle that a current flowing in a conductor sets up an induced current around the conductor. The artificial electromagnetic field is commonly produced by passing alternating current through a horizontal or vertical loop of insulated cable, from which waves spread out in all directions; if any conductive formation, such as an ore-body, is present underground it produces a secondary induced field which can be thoroughly investigated at the surface by reception coils. A great advantage of this inductive method is its effectiveness in districts where the ores are covered by poorly conducting surface deposits. Moreover, it functions successfully in barren mountainous regions, in frozen and snow-laden areas, over ice-covered lakes, and in deserts, and is especially suitable for the intensive examination of tracts where mineralisation is suspected on other geophysical evidence.

As the location of mineral deposits becomes more difficult the demand for geophysical help will grow, but much more research is still required on the technique of this modern science of prospecting and on the geological interpretation of its results before it can be expected to provide consistently reliable evidence.

The Estimation and Classification of Ore Reserves

After mineral deposits have been discovered, careful exploration is necessary to determine their character, shape, size, and prospective tonnage. When a mining company announces the reserves of ore in its concession or mine, it usually refers to the quantities of economically-extractable ore proved or partially proved by survey, drilling, and underground development, and does not include the additional possible tonnages of mineral that may be present but has not been proved. To the nation, however, both the known and unknown ore are involved in the sum of its mineral resources.

One of the most significant developments in the history of the mining industry was the introduction of diamond and churn drilling as means of exploring deposits. Before drills were employed it was common practice to explore and develop deposits by sinking shafts, driving adits, and exposing the ore in underground workings. After the ore-body had been systematically sampled and surveyed, the ore was classified according to the degree of certainty of knowledge into categories such as ' proved ' or ' blocked out,' ' probable,' and ' possible ' ore. The tonnage blocked out referred to ore exposed on at least three sides within reasonable distance of each other, probable ore being reasonably assumed to exist though not actually blocked out, and possible ore being based on the expectancy of unexposed ore. Not uncommonly the value of a mine depends more on the probable and prospective ore than upon the material definitely known to exist. Most mines maintain only a few years' reserves blocked out, but may actually possess large undiscovered resources. Certain gold mines, for instance, have operated for scores of years, although the companies' annual reports have never indicated more than three or four years' reserves. Any attempt to appraise the value of potential, unexposed ore, must rely upon sound geological reasoning founded upon careful structural study and a logical hypothesis concerning the origin of the deposit in question. With a persistent type of deposit, like the English Jurassic iron ores or the manganese beds of Nikopol and Chiaturi, in the USSR, it may be possible to make a rough forecast of the possible tonnage of ore available above a particular depth, but usually it is imprudent to estimate this quantity except in the most general way.

In deposits where the values are discontinuous and irregular it is customary to cal-

culate reserves by adopting some procedure analogous to that outlined above. Where the values are continuous and more or less regular, however, it is generally possible to estimate the reserves on drilling results, without recourse to laborious blocking out and sampling along underground levels. Thus, for example, the reserves of banded ironstone in the Lake Superior region and of bedded iron ores in Yorkshire and Northamptonshire can be adequately proved by boring alone, and the value of alluvial deposits of tin, gold, etc., can be accurately deduced by drilling or, in the case of shallow placers, by pitting. In the United States and South America hundreds of millions of tons of low-grade disseminated copper ore were proved by churn drilling, and little more than a decade ago the reserves in the extensive copper deposits of Northern Rhodesia were largely estimated on the basis of diamond drilling records. Deposits consisting of massive ore, such as the copper-nickel sulphide body at the famous Frood mine, in Ontario, can also be evaluated merely by boring, without any need for tunnelling or shaft sinking. The use of the drill has revolutionised prospecting, and is of inestimable service in helping to determine ore reserves rapidly and accurately, especially in those deposits where the mineralisation is relatively uniform.

Mineral Resources of the World

In the more industrially developed countries and where large-scale mining is being conducted on up-to-date lines, a shrewd appraisal of the ore reserves within certain mining fields is often available. Such estimates have been published concerning the nickel reserves of Ontario, the pyrite deposits of Spain, the copper resources of Northern Rhodesia, North America, and Chile, and the manganese ores of the USSR. On the other hand, where mining is still being pursued by primitive methods, as in parts of China and South America, there is little precise information obtainable relating to the amount and grade of mineral reserves. Comparatively little is known, for example, concerning the tin and tungsten resources of the Far East and Bolivia, or the antimony reserves of China. Some economic minerals, such as mica, are so erratic in their occurrence that estimates based on the most careful surveys may be of small value, whilst other minerals, including rock salt, are so plentiful that there has been no incentive to evaluate them accurately.

The United States is the only country, unfortunately, which has hitherto provided comprehensive statistics on domestic mineral resources, and similar reviews in other lands are long overdue. Information relating to world reserves of specific mineral raw materials is generally vague and sporadic, and is largely based upon published reports of mining companies, and of geological surveys which are systematically conducted by official organisations in the more advanced countries. Conclusions drawn from such reports, both official and private, are usually of qualitative value only, and a great deal of knowledge is withheld from publication for commercial or political reasons.

Iron and Ferro-Alloy Metals.—Although the average annual world production of *iron ore* in the immediate pre-war period was nearly 200 million tons there is no prospect of any shortage of the metal, at that rate of output, for much more than 100 years, since there are colossal reserves of good quality ore in Brazil, USSR, U.S.A., Sweden, Lorraine-Luxembourg, and elsewhere. Moreover, improved methods of ore treatment will add enormous quantities of lower grade material to the stock of ore available.

The outlook for *manganese* is no less satisfactory, for there are proved reserves sufficient to cover all likely demands for more than a century to come, the principal known sources of supply being the famous deposits of Nikopol and Chiaturi in the USSR, the ores of Postmasburg in South Africa, of the Central Provinces of India, Brazil, and the Gold Coast. Although the consumption of *nickel* has expanded considerably within recent years, the known reserves of the Sudbury district of Ontario are almost certainly able to satisfy world needs for more than 25 years, and development underground is constantly augmenting the proved reserves. A large deposit of nickel ore has been located in Brazil, and important supplies occur in French New Caledonia, the USSR, and northern Finland. Precise information concerning reserves of *chromite* (chromium ore) is lacking, but it is clear that the resources of Turkey, South Africa, Southern Rhodesia, and the Soviet Union are quite capable of meeting the requirements of several more generations. Hundreds of millions of tons of chromite are said to exist in the Transvaal, where the deposits are still comparatively undeveloped. Reserves of *tungsten* are little known, but there is no likelihood of a serious dearth for many more years. China, the leading producer during the past two decades, has large resources, and the world-wide search now being conducted for tungsten ores may well result in a substantial increase in the known reserves. The greatest *molybdenum* deposit in the world, that of Climax, Colorado, has reserves enough to cover all needs for more than 20 years at the pre-war rate of consumption. With regard to

vanadium there appears to be no danger of a shortage for a long time, for large reserves are indicated, especially at Minasragra in Peru, and at Broken Hill, Northern Rhodesia. Extensive vanadium-bearing formations have recently been identified in Idaho, which promise to become a principal source of the metal, and increasing quantities of vanadium are being recovered from oil refineries and from soot collected by ships burning Venezuelan and Mexican fuel oil. *Cobalt* supplies are assured for scores of years, the metal being obtained chiefly as a by-product of the copper ores of Northern Rhodesia and the Belgian Congo.

No serious deficiency of iron or of the main ferro-alloy metals need be feared during the present generation, even if no further ore-bodies are discovered.

Base Metals.—The proved reserves of *copper* are alone sufficient to satisfy world requirements for about 40 years at an average annual production of 2 million tons of metallic copper, with the deposits of Chuquicamata (Chile), Northern Rhodesia, Belgian Congo, and the U.S.A. as the dominant sources of supply. It has been asserted that there will be a shortage of *lead* in the United States, now the leading producer, within this or the next generation. Although the proved reserves of lead ore may only be adequate for little more than 20 years, the situation is fortunately relieved to a large extent by the high percentage recovery of secondary, scrap lead. A few years ago the total *zinc* reserves were estimated at more than 50 million tons of metal, equivalent to about 30 years' supply at pre-war rates of consumption. Several established zinc mines are already strained to the limit, but the great Australian deposits of Broken Hill, New South Wales, and of Mount Isa, Queensland, promise to be dependable sources of both lead and zinc for many more years.

Little specific information has been issued concerning world resources of *tin*, since few operating companies ever block out reserves to cover extended future working. Plentiful supplies of alluvial tin still remain in the surface deposits of Malaya, Netherlands East Indies, and the Belgian Congo, but with the gradual depletion of these reserves lode-mining will doubtless become the chief source of the metal. The future of tin production is more uncertain than that of most metals. There has been a phenomenal acceleration in the demand for *aluminium* during the past decade, especially for use in light alloys. The known sources of bauxite, the principal ore of the metal, have been roughly computed to contain 1,000 million tons, the chief accumulations being in Hungary, the Gold Coast, British and Dutch Guiana, France, and Yugoslavia. These reserves would be enough to provide 2 million tons of aluminium annually for more than 100 years. Almost inexhaustible supplies of aluminium could be won, if necessary, from deposits of leucite and nepheline (silicates), and alunite (a sulphate), and research into the commercial recovery of the metal from clays are likely to meet with ultimate success. There is virtually no limit to the available resources of *magnesium*, for this important light metal can be profitably extracted from sea-water and natural brines, as well as from magnesite, dolomite, magnesium chloride, etc. The Almaden mine, in Spain, has sufficient proved reserves of *mercury* ore to cover the entire world requirements for at least another 100 years at the maximum pre-war rate of usage, and although knowledge concerning *antimony* ore reserves are vague, it is believed that China alone could produce enough of this metal to meet all likely needs for more than 50 years.

Miscellaneous Minerals.—From the great copper-nickel deposits of Ontario, and from the alluvial gravels of the Urals, this generation will doubtless receive most of its *platinum*, and the low-grade ores of the Transvaal are capable of supplying any envisaged further requirements. No anxiety need be felt with regard to *titanium*, for the beach sands of Travancore in India, and the massive ores of Southern Norway and the Ilmen Mountains are alone capable of meeting the probable demands for scores of years. Proved reserves of *sulphur*, the most important single commodity in the chemical industry, are more than adequate to cope with normal consumption for the next 50 years; great quantities of native sulphur occur in the salt-dome areas of Texas and Louisiana, in Sicily, and in the Caspian Sea region, and immense deposits of pyrite (FeS_2) lie in Southern Spain and elsewhere.

The principal fertilisers, *phosphates*, *potash*, and *nitrates* are known to exist in sufficient abundance to satisfy world requirements for hundreds of years. Enormous deposits of phosphate rock occur in the United States, Northern Russia, Morocco, Algeria, Tunisia, Poland, and the Pacific Islands; of potash salts in the renowned deposits of Stassfurt in Germany, Solikamsk on the slopes of the Urals, Alsace, Poland, Spain, and the U.S.A., in addition to the inexhaustible supplies contained in natural brines, the Dead Sea, and the oceans themselves; of natural nitrates in Chile, of ammonium sulphate by-products from coal, and of synthetic nitrogen from the atmosphere.

Of *gypsum* and *anhydrite*, *fluorite*, *borates*, *rock salt*, *barite*, *asbestos* and *diatomite* there are enough reserves in widely scattered areas to

outlast the present century. The proved *diamond* resources are not large, but it would be surprising if the gravels of the Belgian Congo, Angola, South-west Africa, Sierra Leone and the Gold Coast proved incapable of contributing a further 25 years' supply of industrial stones. *Mica* occurrences are so irregular and sporadic that it is impossible to calculate their reserves with any degree of accuracy; this mineral, more perhaps than any other, is 'where you find it.' At the present rate of production the ascertained reserves of *gold* and *silver* are likely to approach exhaustion within the next 25 years, unless it becomes economical to mine lower grade ores than at present.

In short, for many metallic and non-metallic minerals the known resources are sufficient to last more than 100 years at the normal pre-war rate of consumption; for others, including lead and zinc, gold and silver, diamonds, tin, and mica, the proved reserves may be exhausted within the present generation, and though the possibilities of discovering new sources of supply during that period are reasonably good, the accelerating drain on the resources already located cannot fail to cause some concern.

The Importance of Certain Alloys, and of Minerals New to Industry

The great technical progress achieved in the engineering industries during the past 60 years has been largely due to the use of alloy steels. Each of the principal ferro-alloy metals, manganese, chromium, nickel, tungsten, molybdenum, vanadium, and cobalt is a key metal, as essential to the steel industry as yeast is to bread. Without them a nation would be virtually defenceless in modern war.

Manganese is indispensable in the making of sound steel, about fourteen pounds of manganese being required for every ton of steel manufactured. In addition to its primary function of removing oxygen and sulphur from the molten iron ore, manganese also imparts many desirable qualities to steel. Manganese steel is unusually tough and resistant to abrasion, and is especially suitable for rock-crushing and excavating machinery, curved rails, switches and crossings. Little of the total amount of manganese consumed enters into the composition of the final steel, most of it being dissipated in irrecoverable form in the slag.

Chromium, probably the most important of of the ferro-alloy metals, endows steel with additional strength, hardness, and resistance to chemical corrosion, these qualities being retained even at moderately high temperatures. The amount of chromium added varies from a fraction of one per cent. up to 50 or 60 per cent. with the purpose of the steel, which may be for armour plate or armour-piercing shells, ball bearings, stainless steel, oil refinery stills, and so forth. One of the most popular steels, with a wide range of application, has 18 per cent. chromium, 8 per cent. nickel and the remainder low carbon steel. *Nickel* alloys are among the most satisfactory known for parts subjected to corrosion, shock, temperature variations, heavy loads, and abrasion. Low-nickel steels, with less than 7 per cent. nickel, are preferred for the moving parts of engines, for architectural and bridge construction, and for building automobile and locomotive bodies, axles, connecting rods, etc. High-nickel steels, with 7 to 35 per cent. nickel, combine strength with remarkable resistance to corrosion and heat. These stainless steels are utilised for furnace parts, marine fittings, chemical apparatus and cooking utensils. Low-expansion nickel alloys are of great value for length standards, measuring tapes, precision instruments, and various control devices for temperature and electricity.

Whereas manganese is used for making all kinds of steel, and both chromium and nickel are incorporated in an innumerable variety of alloys, the application of *tungsten* is confined to a few special types of alloy steel, and especially for high-speed cutting steels, which retain their hardness even at red heat. The best quality tool steel contains about 18 per cent. tungsten, together with some chromium and vanadium. With such steel, a cutting tool can be operated several times as fast as a tool made of ordinary carbon steel, and much deeper cuts are possible. For military purposes tungsten alloy steels are used for armour plate, armour piercing projectiles, rifle barrels, and heavy ordnance. *Molybdenum* makes steel shock resistant, tough, and exceptionally hard, and is frequently employed as a substitute for tungsten in high-speed steels. Low-molybdenum steels, with less than 1 per cent. Mo, are estensively used in the automobile industry, railway forgings, and agricultural implements, whereas high molybdenum varieties are commonly used for rustless steels, dies, high-speed tools, and permanent magnets. *Vanadium* steels are pre-eminent among those resisting fatigue, shock, and twisting stress, and are consequently in demand for axles, shafting, and springs, and wherever parts are subjected to repeated stresses. *Cobalt*, in addition to being of particular value in permanent magnets, is also employed as an alloy metal in corrosion-resistant and stainless steels, suitable for surgical instruments, razor blades, and the like. It may be added, incidentally, that within recent years a super-hard cutting tool

has been developed, consisting chiefly of tungsten carbide with cobalt as a binder. This material is the hardest known cutting agent next to the diamond, and is capable of cutting manganese steel, glass, and porcelain, which no ordinary steel can touch. Moreover, these carbide tools function admirably at high temperatures, and last up to 100 times as long between sharpenings as high-speed steels.

The craving for speed in transportation is largely responsible for the spectacular increase in the consumption of the light-weight metals *aluminium* and *magnesium* during the past decade. These metals combine lightness with strength and resistance to atmospheric corrosion, in addition to which aluminium possesses such high electrical conductivity that it rivals copper in the electrical industry. Magnesium-aluminium alloys are now used in great quantities in aeroplanes, motor cars, and trains, while flares and incendiary bombs account for a considerable part of the war demand for magnesium metal.

Among the large number of other metals and minerals which have leapt from obscurity into prominence during the past 20 years, the following are noted briefly :

Andalusite, an aluminium silicate, especially for making porcelain sparking-plug cores and, in Scandinavia, as a source of aluminium metal. *Bentonite*, a clay mineral that often swells enormously in water, is unexcelled as a bleaching clay and as a filter in oil refining, and is being extensively used in the United States in foundry moulding and core sands, for rotary oil drilling mud, and in many other ways. From a negligible quantity 17 years ago production in America now exceeds 250,000 tons annually. *Beryl* is the sole commercial source of the infant metal beryllium, which imparts surprising tensile strength and fatigue-resistance to copper. Copper-base beryllium alloys are in demand for vibrator springs, valves, electrical contacts, bushings, and diaphragms, and because of their non-sparking properties they are welcomed in munition factories and oil refineries. *Borax* consumption has trebled during the past two decades, principally for heat-resisting glass of the Pyrex type, porcelain enamelware, and as a flux for welding and soldering.

Cadmium output has multiplied more than six-fold since 1927, the metal being used chiefly for rust-proof electroplating on steel, and in high-pressure bearing alloys. Metallic *calcium*, a newcomer to industry, is a valuable deoxidiser in refining magnesium, aluminium, nickel and various non-ferrous alloys, and an efficient hardener of lead-base bearing metal. *Cerium* is alloyed with 30 per cent. iron to form ferrocerium, an alloy used as 'flints' for cigarette lighters ; the metal acts as a scavenger in removing oxygen, nitrogen and sulphur impurities from molten iron. *Indium*, obtained from zinc residues, is now utilised for plated bearings in the automobile and aircraft industries, as a precious metal alloy, and as a corrosion-resisting dental alloy.

Kyanite has recently gained favour as an aluminous refractory material in the manufacture of brick and other refractories for glassworks, and for sparking-plug porcelains. *Ilmenite*, derived mainly from the beach sands of Travancore in south-west India, is now produced in abundance for making titanium white, the whitest of all paints, with twice the opacity of zinc oxide and three times that of lead oxide. *Lithium*, the lightest of metals, finds increasing employment in storage batteries, various light alloys, enamels and, in the form of chloride, in dehumidifying air for air-conditioning. *Nepheline* has achieved prominence during the past ten years by virtue of its use in glassmaking and, in the Soviet Union, as a substitute for bauxite in the aluminium industry. Within the same period there has been a phenomenal increase in the production of piezoelectric *quartz crystals* suitable for radio and telephone equipment, especially for frequency control in wireless transmission and for long distance telephone and cable service ; these crystals, obtained from Brazil, are now also being incorporated in extremely accurate clocks for observatories.

Selenium, a by-product obtained from copper refineries, is used chiefly for making red signal glass and for decolourising green glass ; owing to its property of conducting electricity only when exposed to light, selenium is employed in television apparatus, and in automatic devices for lighting street lamps, buoys, and burglar alarms. *Tantalum* and *niobium*, because of their affinity for gases, are widely used for absorbing all traces of gases from radio valves and vacuum tubes ; tantalum is in growing demand for the manufacture of cutting tools and acid-resisting chemical ware, and the carbide is almost as hard as the diamond : niobium improves certain weldable high-speed and stainless steels. The newcomer, *tellurium*, toughens rubber and imparts to lead increased hardness and resistance to wear and corrosion. *Vermiculite*, a mica-like mineral which expands rapidly on heating, claims growing attention as a heat and sound insulator when mixed with Portland cement, concrete, and plasters.

Scrap Metals

The depletion of the world's mineral capital is being offset more and more by the recovery and return to industry of important quantities of scrap metal, such as iron, copper,

lead, and tin. In addition to the old scrap consisting of disused material arising from obsolescence, accident and wear, a great deal of secondary metal is now recovered from drillings, turnings and rejects produced in engineering shops.

During periods of economic depression and during the emergency of war, countries become salvage-conscious, and a considerable part of their metal requirements may be garnered from accumulated scrap. Thus, during the post-war depression of 1920 to 1923, more than 60 per cent. of the copper sold in the United States was of secondary (scrap) origin, and in the slump ten years later 80 per cent. of their domestic copper needs were supplied from scrap metal. In that country, it is estimated that between 1929 and 1938 about 75 per cent. of the iron used in the manufacture of steel was obtained from various forms of scrap, and in 1941 more than 45 million tons of secondary iron and steel were consumed in blast furnaces and steel-making furnaces.

During 1939 non-ferrous scrap in the United States accounted for the following percentages of the total respective metal consumptions: copper 66, lead 36, zinc 30, aluminium about 25, platinum 45, antimony 45, tin 41, and nickel about 4. Although no precise information was published concerning the secondary recovery of chromium and tungsten there was undoubtedly a considerable return of used material, and the amount has since increased. In 1941, approximately 1,600 tons of secondary magnesium, and 5,000 tons of nickel were salvaged from scrap.

The importance of recovering metals from scrap is still inadequately recognised. With the exception of the United States no country issues figures of secondary metal production, and the subject remains a great blind spot of the world's metal economy. There is an urgent need for the institution of measures that will ensure a maximum recovery of scrap, and for the gathering of international statistics relating to the available supplies of scrap metal, according to a universally agreed basis of classification. Clearly the aim should be to collect all possible data concerning stocks of scrap for correlation with details of world mineral supplies, in order to formulate schemes for the proper utilisation of the total mineral and metal resources.

Conservation of Mineral Resources

Although there is no danger of an immediate shortage of any particular mineral or metal, the fact that mineral resources are irreplaceable, wasting assets which are being rapidly depleted raises the question of their conservation. The aim of any conservational policy should be to prevent waste and promote the more efficient use of mineral raw materials, rather than to hoard them for posterity. Scientific research designed to improve methods of prospecting, mining, concentration, and mineral usage, coupled with an international policy of exploitation and distribution are the best insurance for the future of the mineral industry.

Geologists have much to learn concerning the genesis of mineral deposits, the structural control of mineralisation, and the interpretation of surface phenomena related to concealed ores, whilst advances in the technique of geophysical prospecting are certain to result in the finding of new mineral deposits. The geological study of deposits while mining is actually in progress often leads to an increase in reserves and to more economical working, arising from a fuller understanding of the structure of the ore-bodies. Observations made at operating mines greatly assist in the search for similar nearby deposits, and the microscopical examination of complex ores may provide crucial evidence leading to the adoption of more efficient methods of metallurgical treatment.

Clearly no mining company should be allowed to 'pick the eyes' out of a deposit, by extracting high-grade ore so as to jeopardise the subsequent winning of temporarily unpayable leaner ore. Organisations with powerful financial backing are less likely to indulge in this pernicious practice than small producers who may be unable to afford to take long-range views.

Improvements in mining machinery and other appliances, in labour and living conditions at the mines, and in methods of extracting ore with a minimum of wastage, all facilitate the exploitation of leaner ores. Better ventilation and the installation of refrigerating plants to lower air and rock temperatures underground allow deeper mining, and thus augment the accessible reserves. The application of selective flotation processes to the concentration of ores has revolutionised the practice of ore treatment, and promoted hundreds of millions of tons of low-grade material into the category of profitable ore. Further advances in this direction are constantly being registered, and important advances are being made in the purification of smelter and other gases whereby by-products formerly wasted are now recovered, such as cadmium from zinc ores, sulphur and arsenic from copper smelting, and nitrates from the coking industry. Furthermore, other minor metals, such as bismuth, indium, selenium, and tellurium, valuable newcomers to industry, are being obtained in growing quantities as

by-products during the refining of copper and other major metals.

From the standpoint of conservation it is desirable to emphasise such factors as the relative importance of those minerals which are in short supply, e.g. tin, those for which there are no wholly effective substitutes, e.g. mica, and those which are destroyed when once used, e.g. manganese. Economy in the use of metals may be exercised by such methods as the adoption of reinforced concrete in place of steel, and of special-purpose ferrous alloys to improve the efficiency of steel and prevent the wastage of iron. Protective anti-corrosion films and plating preserve the underlying metal from decay, and better structural designs may permit a reduction in the weight of beams and girders. The use of piezoelectric quartz crystals in long distance telephone communication enables hundreds of messages to be transmitted simultaneously over a single wire, and thus helps to conserve mineral resources.

By concentrating, smelting and refining mineral raw materials at or near their place or origin, so that only the final products need be exported to the consuming countries, a considerable saving in resources may often be effected. This would generally lead to economy in transport costs, indirectly permitting the mining of leaner ores, and greatly diminish the tonnage involved in the carriage of crude products. It would seem logical, therefore, that minerals should at least be concentrated near the sources of supply, unless economic considerations dictate otherwise.

The employment of substitutes must play a significant role in conservational policies. Many metals and minerals are virtually indispensable, since no fully adequate substitutes have yet been found for them. Thus, manganese is practically essential for the deoxidation of steel ; chromium and nickel, for special alloy steels ; tungsten for electric light filaments ; cobalt, for magnet steel ; copper, for brass, bronze and similar alloys ; mercury, for firing explosives ; lead, for ammunition and storage batteries ; aluminium and magnesium, for light alloys ; mica, for electrical condensers, etc. ; and asbestos for high temperature insulation. On the other hand, the comparatively rare metal, platinum, may be replaced by fused silica in the manufacture of sulphuric acid ; molybdenum may usurp the place of tungsten in high-speed steels ; enamel coatings and glass may oust tin in food containers ; and synthetic nitrogen may supplant Chilean natural nitrate.

Within recent years plastics and synthetic resins of various kinds have gained wide popularity, serving to replace aluminium, chromium, zinc, and glass for many purposes. Unquestionably these new materials will continue to gain favour, though it remains to be proved that they will effect such radical changes in the world's mineral requirements as are envisaged by their most enthusiastic advocates. War has stressed the importance of salvaging scrap, and it is hoped that the value of secondary metal in conserving mineral resources will be more universally appreciated in the post-war era.

Some International Aspects of Mineral Resources

The interdependence of nations on mineral supplies is inescapable, since no country can be wholly self-sufficient, and none can prosper materially unless it has access to those mineral raw materials which are necessary for its industrial development. Probably not less than one-third of the annual world output of minerals is exported from the countries of origin and so becomes involved in international trade, the interruption of which would imperil world peace.

Even though the tendency in many countries towards the nationalisation of mineral resources may well be accentuated in the post-war period, there is an urgent need for these resources to be regarded as a world rather than a purely national problem. The initial step in an international consideration of minerals and metals should be one of stock-taking, with the object of completing an inventory of proved and probable world resources so that an effective policy of exploitation and distribution can be formulated for the benefit of all peoples. Full assessment of these resources should be undertaken as soon as feasible after the cessation of the present hostilities, when it is hoped that each country will set up a Resources Board to compile information relating to its own domestic supplies, details of which would be placed before an International Organisation. Systematic planning of mineral production, allocation, and consumption is required to ensure the most effective use of our mineral heritage.

The proved reserves of certain minerals may be exhausted during the present generation, but with continuous research aimed at improving methods of prospecting, mining, ore concentration, refining, and scrap metal collection, and with the more efficient use of mineral products, the bogey of a shortage of total world mineral supplies recedes to haunt a future generation. The pressing need of our time is to distribute the supplies equitably and to use them in the most efficient manner, and not to curtail production as a means of conserving resources.

REPORT OF THE COUNCIL TO THE GENERAL COMMITTEE FOR THE YEAR 1943–44

(NOVEMBER 1944)

OBITUARY

THE Council have to deplore the loss by death of the following office-bearers and supporters :—

Prof. C. G. Barkla, F.R.S.
Mr. H. H. Brindley
Prof. A. H. R. Buller, F.R.S.
Dr. J. McKean Cattell
Dr. F. D. Chattaway, F.R.S.
Sir J. B. Farmer, F.R.S.
Dr. W. H. Hatfield, F.R.S.
H.H. the Maharaj-Rana of Jhalawar
Dr. A. Lauder
Sir Henry Lyons, F.R.S.
Dr. R. R. Marett
Prof. F. Newall, F.R.S.
Prof. Sir Edward Poulton, F.R.S.
Sir David Prain, C.M.G., C.I.E., F.R.S.
Prof. J. H. Priestley
Dr. F. L. Pyman, F.R.S.
Dr. W. L. Sclater
Prof. A. Stansfield
Sir Aurel Stein, K.C.I.E., F.B.A.
Dr. Ethel N. M. Thomas
Prof. W. M. Thornton
Dr. F. J. W. Whipple
Prof. L. R. Wilberforce

REPRESENTATION

The Association was represented at the funeral of Sir Edward Poulton, ex-President, by Prof. Sir John Myres, F.B.A.

The Association was represented by the President and other officers at a private conference on Research in Industry, held by Nuffield College, Oxford.

As an outcome of the Divisional Conference on Science and the Citizen, held in March 1943, the President headed a deputation to the B.B.C., which was sympathetically received by the then Director-General (Mr. R. W. Foot) and members of his staff, with whom a full discussion took place on future arrangements for broadcasts on scientific subjects and the best means for securing such arrangements.

The President accompanied a deputation representative of the learned societies occupying premises in Burlington House, which was headed by Sir Henry Dale, Pres.R.S., and laid before representatives of H.M. Government the urgent need for more adequate accommodation for these and other societies.

At the P.E.N. Commemoration of the tercentenary of the publication of Milton's *Areopagitica*, the following were appointed to represent the Association : Dr. M. Davidson, Prof. H. Dingle, Prof. E. T. Whittaker, F.R.S. Dr. A. P. M. Fleming, C.B.E., represented the Association at the Manchester Literary and Philosophical Society's commemoration of the centenary of the death of John Dalton.

COMMUNICATIONS

Messages have been received from Academia Sinica ; the National Science Society of China ; and the Soviet Scientists' Antifascist Committee. Replies have been forwarded on behalf of the Association.

The visit of Professor A. V. Hill, M.P., F.R.S., to India, afforded opportunity for the conveyance of a message to Indian Science from the President of the Association.

After the liberation of Paris, the Secretary was enabled, through the courtesy of M. Louis Rapkine, of the Mission scientifique française en Grande-Brétagne, to address a letter of goodwill to Prof. A. Verne, Secretary-general of l'Association française pour l'Avancement des Sciences. A message of greeting and hope for the early renewal of active relations between the two Associations was subsequently received by the Council from Prof. Verne on behalf of the Preisdent and Bureau of l'Association française, and a reply was sent on behalf of the Council.

Members of the Council addressed a message to the President on his eightieth birthday, and the following reply was received :—

'I am very grateful for the kindly message which you have been good enough to send to me on the anniversary of my 80th birthday on Saturday last, 29 January. When I became a Life-Member of the Association many years ago, I did not for a moment contemplate the possibility of being honoured by election to the Presidency, or, indeed, to live long enough to hold this office in my 80th year. I need scarcely say to all members of the Council how very highly I appreciate their personal friendship and how strongly I believe that we have a distinctive part to play in educating the public as to the meaning of the spirit and service in science in modern life. There are now many signs of such an awakening of public interest, and the Association is performing a valuable national service in extending it. No other scientific body is better fitted by its constitution and membership to carry on this work, but we cannot do so with full efficiency without further financial resources. We may confidently hope that these will be provided in due course.'

R. A. GREGORY.

DIVISION FOR THE SOCIAL AND INTERNATIONAL RELATIONS OF SCIENCE

A meeting of the Division, jointly with the Indian group of the Royal Institute of International Affairs, was held at Chatham House, by kind permission of the Institute, on Friday, November 10, to receive the Indian scientists visiting Britain. Sir Richard Gregory, Bt., F.R.S., was in the chair, and the meeting was addressed by Prof. M. N. Saha, F.R.S., and others. Members of the Council and of the Association's delegation to India in 1938 entertained the visitors to luncheon before the meeting, and the Institute gave tea at Chatham House afterwards.

Preparations have been made for a conference on 'The Place of Science in Industry,' to be held in January 1945; and it is hoped to arrange other conferences later in that year.

Reports of the Divisional Committees on Scientific Research on Human Institutions, and on Post-war University Education, have been approved by the Council and have been published.

Publication

The thanks of the Association have been expressed to the Royal Society for a further grant of £400 towards the expenses of publication, made by the Royal Society from the Rockefeller Fund administered by the Society for that purpose.

It has been reported by the publishers, Penguin Books Ltd., that the sales of the volume on *Science and World Order*, prepared with the consent of the Council, amounted to 58,186 down to June 30, 1944.

The next Annual Meeting

The Council regret that, after inquiry, it does not appear possible that an Annual Meeting of the Association should be held in 1945. Nevertheless the Council have thought it desirable to resume the joint meetings of Organising Sectional Committees formerly held early in each year, and have taken steps to resuscitate these committees with a view to a meeting in January 1945 [see note on following page].

Future Organisation

The organisation and administration of the Association have been considered in detail, and a report on these, together with proposed amendments of the Statutes and Regulations, will be circulated separately to the General Committee [see note on following page].

General Officers and Council

The *General Officers* are nominated by the Council for reappointment.

General Treasurer.—Sir Harold Hartley, K.C.V.O., F.R.S.

General Secretaries.—Prof. F. T. Brooks, F.R.S., Prof. Allan Ferguson. The Council hope to nominate a third General Secretary shortly.

Council.—Sir Richard Allen has resigned from the Council, and has received the Council's sincere thanks for his services. Sir John Russell, F.R.S., and Mr. E. W. Salt, M.P., have been added to the Council. Otherwise it is recommended that advantage be again taken of the Lord President's licence to modify in certain particulars action prescribed by the Statutes, and that no further change be made in the personnel of the Council.

Finance

The General Treasurer's Account for the financial year ending March 31, 1944, has been audited and presented to the General Committee. Grants have been made to Research Committees in accordance with the schedule appended to the Account.

Grants to Research Committees, 1944–5

The following grants have been approved:—

	£
Seismological Investigations Committee	100
Mathematical Tables	25
Plymouth Laboratory	50
Zoological Record	50
Freshwater Biological Station	75
Algae and Protozoa	25
Kent's Cavern	5
Bird Behaviour	20
	£350

A grant of £190 for the printing of mathematical tables (Airy, £110, and Legendre, £80) was allowed from the Caird Fund last year, but not drawn. The Mathematical Tables Committee expects to use the grant before August, 1945, and revises its estimate for the Airy tables to £130. Some increase, not yet known, in the cost of the Legendre tables is also expected—say 210

Total list £560

Grants from the Leicester and Leicestershire Fund have been made as follows:—

To Dr. J. M. Reynolds, Department of Biology, College of Technology, Leicester, £25; to Dr. J. D. Smyth, Department of Zoology, University College, Leicester, £30; to Mr. J. L. Crammer, a third and final grant of £30.

Down House

Conditions at Down House have not materially altered during the past year. It remains closed to the public, but continues to serve purposes of local importance in connection with the war.

The following gifts have been gratefully acknowledged:—from Dr. W. A. Richardson, books; from Mr. Bernard Darwin, a portrait of William Erasmus Darwin; from Dr. R. Vaughan Williams, O.M., portraits of Dr. Erasmus Darwin, by Wright, and of Charles Darwin in youth.

The precipitation for the year 1943 read from the standard rain-gauge was 27·27 ins. That of every month excepting January and May was subnormal.

The experimental bed of *Lythrum salicaria* (Purple Loosestrife) cultivated in the garden last year at the instance of Prof. R. A. Fisher, F.R.S., and Dr. K. Mather, is being maintained.

In the present difficult conditions connected with labour, the grounds have hitherto been fairly well maintained. The recent calling up of a member of the staff aged 18, cannot but cause greater difficulty in the ensuing year, if, as has been found so far, it remains impossible to replace him. He had rendered excellent service for 3½ years. The present staff now consists of three members (including the Secretary) who would in normal conditions have retired under the age-limit. Any other labour which it is possible to employ is casual.

Consideration has been and continues to be given to the renovation of the property as soon as

conditions permit. The need for this will be substantial, and so will the cost, even if conditions remain as they are now. Apart from any war damage which may be covered by insurance, it is certain that the fabric of the house, which has not infrequently been shaken, will need expert inspection, and that some of the temporary strengthening carried out as part of the precautions undertaken early in the war (and justified since) will have to be replaced by permanent structural work. Complete redecoration will be necessary, and the stored furniture from the Darwin rooms will probably need expert inspection and renovation. But for the war, it would have been recommended before now that the property should be connected to the main drainage system of the district (not far distant), as the existing house system is obsolescent. The grounds will need extensive work upon them.

In these circumstances the fact that the General Treasurer's accounts of recent years have shown small balances of revenue over expenditure on the house account, and that a balance of the Herbert Spencer Fund has been transferred to a rehabilitation fund, is gratifying ; but it cannot be doubted that necessary expenditure on the property as soon as conditions permit will largely exceed any moneys available from these sources. It is impossible at present, however, to formulate definite estimates.

[NOTE.—Meetings of the General Committee, to consider the revised Statutes and Regulations, and of such Sectional Committees as were available, were actually held in April 1945. It is hoped to publish an account of the proceedings in a subsequent issue.]

THE LATE SIR BUCKSTON BROWNE, F.R.C.S.

ON February 23, 1945, the Council adopted the following resolution :

That the Council of the British Association record their deep regret at the death of an outstanding benefactor of the Association, from whom the Association received the gift of Down House, the home of Charles Darwin. By his generous act Sir Buckston Browne laid upon the Association the honourable custody of a lasting memorial to one of the greatest names in the advancement of science.

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